IDAHO POWER
An IDACORP Company

Proposal to Initiate Negotiated Rule Making for Site Specific Temperature Criteria for Fall Chinook Salmon Spawning in the Hells Canyon Reach of the Snake River

Final

(Revision 1)

Idaho Power Company

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1. INTRODUCTION

In 2006, Idaho Power Company (IPC) submitted a proposal for Site Specific Criteria (SSC) to the Idaho Department of Environmental Quality (IDEQ) for fall Chinook salmon (*Oncorhynchus tschawytscha*) spawning temperature for the Snake River below the Hells Canyon Complex (HCC). The purpose of the proposal was to initiate an informal forum to discuss SSC preliminary to a formal petition for a rulemaking. The proposal was submitted for review to IDEQ only because the Oregon Department of Environmental Quality (ODEQ) indicated it preferred to participate in the process as an observer. IPC proposed a Snake River fall Chinook salmon spawning criterion not greater than 16.5 C as a daily maximum temperature on October 23 and subsequent daily maximum temperatures not to exceed levels equal to a 0.2 °C daily rate of decline through November 10. From November 11 through April 15, the daily maximum temperature was not to exceed 13 °C. These SSC were to be applied to the Hells Canyon Reach, the Snake River from Hells Canyon Dam [river mile (RM) 247.6] to the Oregon/Washington border (RM 176.1)[1].

The IDEQ held a meeting to discuss the technical merits of IPC's SSC proposal. In attendance were: IDEQ, ODEQ, U.S. Environmental Protection Agency (EPA), National Marine Fisheries Service (NOAA), U.S. Fish and Wildlife Service (USFWS), Idaho Department of Fish and Game (IDFG), Columbia River Inter-Tribal Fish Commission (CRITFC), Nez Perce Tribe (NPT), Idaho Rivers United (IRU), and American Rivers (AR). The group raised several issues including a concern that the proposed SSC was at the ―edge of the envelope" for fall Chinook salmon and that the proposal would result in a standard with no inherent added protection, particularly when the resource is a species protected under the Endangered Species Act (ESA). Specifically, one concern was temperature changes downstream relative to the compliance location of Hells Canyon Dam. If water temperatures were to increase in a downstream direction, then compliance may not ensure that fall Chinook salmon embryos would not be exposed to temperatures higher than the standard. Further inquiry was made about accuracy of equipment used to measure temperature both in the river and at the compliance point and the accuracy of the temperature equipment involved in the Battelle study used as primary supportive information of the proposed SSC (discussed later in this document). Others also noted a desire to include an explicit margin of safety to ensure protection of the resource.

IPC has considered the comments and concerns expressed in reaction to the first proposal and continues to believe that the available information warrants a SSC greater than the existing Idaho and Oregon

[1] This proposal, at times, refers to the Hells Canyon Reach. This is intended to reference the Snake River from Hells Canyon Dam to the Salmon River confluence.

numeric criteria of 13 °C maximum weekly maximum (MWM)[2] and 13 °C seven-day average maximum[3], respectively, (standards which have been interpreted by IDEQ and ODEQ as functionally similar), but that a sufficient margin of safety could be incorporated. The purpose of this document is to provide technical support for this revised proposed SSC for temperature for Snake River fall Chinook salmon spawning and incubation below Hells Canyon Dam that is protective of the resource consistent with IDAPA 58.01.02.070.07 and OAR 340-041-0028(13).

This revision of the proposed SSC was made after review of the initial proposal by Dr. Charles C. Coutant and Dr. Dudley W. Reiser. Their letters of concurrence of this proposal are attached as Appendices 1 and 2, respectively.

The proposed SSC in Idaho and Oregon (presented again in greater detail in Section 3, with rationale in Section 4) that would be protective of Snake River fall Chinook salmon spawning are:

Proposed Amendment to Idaho IDAPA 58.01.02

286. SNAKE RIVER, SUBSECTION 130.01, HUC 17060101, UNIT S1, S2, AND S3; SITE-SPECIFIC CRITERIA FOR WATER TEMPERATURE

A maximum weekly maximum temperature of fourteen and an half degrees (14.5C) applies from October 23rd through October 31st and a maximum weekly maximum of thirteen degrees C (13C) applies from November 1st through April 15th to protect fall chinook spawning and incubation in the Snake River from Hell's Canyon Dam to the Salmon River.

2 Idaho DEQ defines the Maximum Weekly Maximum Temperature as the single highest weekly maximum temperature (WMT) that occurs during a given year or other period of interest, e.g., a spawning period. The WMT is the mean of daily maximum temperatures measured over a consecutive seven (7) day period ending on the day of calculation. When used seasonally, e.g., spawning periods, the first applicable WMT occurs on the seventh day into the time period. IDAPA 58.01.02.52.

3 Oregon DEQ defines the Seven-Day Average Maximum Temperature as a calculation of the average of the daily maximum temperatures from seven consecutive days made on a rolling basis. OAR 340-041-0002(56).

Proposed Amendment to Oregon OAR 340-041-0028(4)

(g) The seven-day-average maximum temperature of a stream identified as having fall Chinook salmon spawning use may not exceed 14.5 degrees Celsius (58.1 degrees Fahrenheit) at the times indicated on Table 121B. The seven-day-average maximum temperature is calculation of the average of the daily maximum temperatures from seven consecutive days made on a rolling basis.

While the main focus of this proposal is the spawning life-stage, effects on other life stages as a result of the standard are also part of the consideration. This document is structured to provide background information on this SSC proposal, the status and life history of Snake River fall Chinook salmon, a description of the existing criteria relative to existing conditions, and the rationale for the proposed SSC. In 2007, IPC developed a Temperature White Paper that provided a comprehensive review of the effects of the HCC on fall Chinook salmon (Groves et al. 2007; Appendix 3). Much of the information presented in this document is summarized from this white paper. Subsequent to the submittal of the White Paper, the NPT filed, on August 30, 2007, with the Federal Energy Regulatory Commission (FERC) a review of the white paper conducted by the CRITFC (Appendix 4). In December, 2007, IPC filed a response with FERC to the CRITFC review that evaluated the principal criticisms made by CRITFC of the white paper (Appendix 5). As part of his review of this SSC proposal, Dr. Charles C. Coutant provided comments (dated June 10, 2010) relative to the August 30, 2007 review conducted by the CRITFC (Appendix 6). Further, as part of evaluating the temperature requirements of fall Chinook salmon, IPC commissioned a study through Battelle that investigated the effects of different thermal regimes on fall Chinook salmon egg incubation, fry development and growth. The findings of that study are also summarized in the white paper; the study was accepted for publication in the Transactions of the American Fisheries Society where it received full peer review (Geist et al. 2006).

2. BACKGROUND

The HCC consists of the Brownlee, Oxbow, and Hells Canyon hydroelectric projects, located from RM 343.0 to RM 247.6 on the Snake River. The Snake River is boundary water between Oregon and Idaho. IPC operates the three hydroelectric projects in the HCC pursuant to FERC license, Project No. 1971, which expired in 2005, and continues under an annual license. IPC filed an application with the FERC to re-license the HCC in July 2003. That application is currently pending before the FERC. In conjunction with the licensing process, IPC has also applied for Section 401 water-quality certification from Idaho and Oregon. IPC has developed the technical documentation necessary for the IDEQ and ODEQ to consider the SSC proposed in this document. Because the Snake River is boundary water, IPC anticipates that the IDEQ and ODEQ will develop a coordinated process to address the issues raised by this proposal.

In July 2003, and revised in June 2004, the IDEQ and ODEQ (2004) issued the Snake River–Hells Canyon Total Maximum Daily Loads (SR–HC-TMDLs) that cover the mainstem Snake River from RM 409 near the town of Adrian, Oregon, to the inflow of the Salmon River at RM 188.2; this river reach includes the HCC. IPC received load allocations through the SR–HC-TMDLs for temperature, dissolved oxygen (DO), and total dissolved gases. The EPA approved the bacteria, pH, pesticides, and total dissolved gases TMDLs in March 2004 and nutrients, nuisance algae, DO, and temperature in September 2004.[4]

2.1. Site Specific Criteria Process

By Idaho statute, the IDEQ may develop new or modified criteria through site specific analysis that effectively protect designated and existing beneficial uses. IDAPA 58.01.02.275. Specifically, IDAPA recognizes that temperature criteria as they relate to specific water bodies are appropriate for adjustment when doing so will fully support the designated aquatic life at a higher temperature. IDAPA 58.01.02.070.07. Likewise, Oregon regulations provide that the ODEQ may establish, by separate rulemaking, alternative SSC for all or a portion of a water body that fully protects the designated use. OAR 340-041-0028 (13). The EPA must approve any final SSC implemented by the states. 40 CFR 131.20(c). While Idaho, Oregon, and the EPA regulations provide the authority to promulgate SSC, they do not fully prescribe the procedure. Therefore, IPC proposes that IDEQ and ODEQ, jointly or separately, engage in a negotiated rulemaking to establish a revised SSC for temperature in the Snake River from Hells Canyon Dam to the Salmon River.

The negotiated rulemaking process for Idaho would include public notice of negotiated rulemaking, two public meetings, publication of the proposed rule on the Administrative Bulletin for public comment, submission of the proposed rule to the Idaho Board of Environmental Quality, review by the Idaho legislature, and submission of the revised rule to EPA for review. This process is expected to take approximately one year.

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[4] Although EPA has approved the TMDLs, IPC has filed a petition for judicial review of those portions of the TMDLs that impose a temperature load allocation on the HCC. That petition is pending in Baker County, Oregon. This petition is independent of that pending legal proceeding.

The collaborative rulemaking process under Oregon rules is similar to the Idaho process, but the resulting rule does not require legislative approval. Any interested person may petition for a SSC rulemaking. ODEQ may hold a public hearing, but regardless must within 90 days approve or deny the petition, or initiate a rulemaking process. If ODEQ proceeds with a rulemaking, it may appoint a collaborative rulemaking committee or advisory committee to develop the rule. Public notice is given in inviting comment on the proposed rule; ODEQ may hold a public hearing to receive comment. Once the rulemaking record is complete, ODEQ may adopt the rule and file it with the Secretary of State. The SSC rule is then sent to EPA for review. This process is likely to take about one year.

2.2. Snake River Fall Chinook Status

Snake River fall Chinook salmon were listed as a threatened species in 1992 under the Endangered Species Act. Many factors led to their protected status, including development on the lower Snake and Columbia rivers and the corresponding necessity for the species to migrate through eight federal hydroelectric projects below the HCC. The HCC's effects on temperature below Hells Canyon Dam are not indicated as factors that contributed to the population decline.[5] However, as NOAA Fisheries has observed, Snake River fall Chinook salmon returns have been significantly higher since 2000 than had been observed in the two preceding decades (Declaration of D. Robert Lohn, Case No. CV01-00640-RE, June 12, 2003). While IPC has not changed project operations in a manner that would alter its effects on temperature, Snake River fall Chinook salmon returns and the number of redds constructed below Hells Canyon Dam have been steadily increasing (Figure 1), with 2009 having the highest redd count (3,476 redds) for Snake River fall Chinook salmon above Lower Granite Dam since intensive redd count surveys began in 1991[6]. Adult numbers have increased from 336 in 1990 to over 15,000 in 2009. The component of natural adults contributing to spawning has also increased substantially and has ranged from a low of 78 in 1990 to a high estimated in 2001 of over 5,000 (Debbie Milks, Washington Department of Fish and Wildlife, personal communication).

[5] The IDEQ in its comments to the IPC's draft license application indicated that it has not identified any evidence that the fall Chinook salmon population below Hells Canyon Dam is impaired by the temporal shift in water temperatures influenced by the HCC. (See the FLA, Consultation Appendix [T. Dombrowski, 2002, "Idaho Department of Environmental Quality Comments on Idaho Power Hells Canyon Complex Draft Application," FERC]).

[6] Weekly helicopter surveys beginning in mid-October and extending through early December have consistently been conducted in all years since 1991 to count and document timing and distribution of redds in the Snake, Clearwater, Grande Ronde, Imnaha and Salmon rivers. In addition, deep-water video searches for redds in the Snake River have continued since 1993. Redd searches have been a coordinated effort by IPC, the U.S. Fish and Wildlife Service and the Nez Perce Tribe.

There are several reasons for the increased abundance. Increased hatchery supplementation is a primary factor[7]; however, increasing returns of non-hatchery salmon and steelhead, including Snake River spring Chinook salmon, Snake River steelhead and Snake River fall Chinook salmon, over the last several years suggest improvements in migration survival and/or ocean conditions. Regional management decisions on harvest levels, and the quality and quantity of habitat are also factors contributing to increased abundance. With the increased fall Chinook salmon returns, there is clear evidence that Snake River fall Chinook salmon are spawning successfully and that current conditions are supporting this beneficial use designated for the Snake River below Hells Canyon Dam. Recent studies demonstrate sufficient habitat in the Snake River to support a further increase in numbers of fall Chinook salmon (Groves and Chandler 2001; Connor et. al. 2001). Recent studies (Geist et al. 2006) also demonstrate that the fall thermal regime with initial spawning temperatures <16.5 °C does not impair survival of incubating fall Chinook salmon. Fall Chinook salmon spawn in periods of declining water temperatures. Fall Chinook salmon spawn in late fall in large mainstem river environments. Their typical life history is that of rearing for a brief period after emergence in early spring, and then migrating to the ocean as an Age-0 fish. These habitat and life history characteristics of fall Chinook salmon are sufficiently different from other races of Chinook salmon (e.g., spring /summer Chinook salmon, *Oncorhynchus tschawytscha*) and other species of Pacific salmon (e.g., sockeye salmon, *O. nerka*) to suggest that temperature preferences or tolerances of other Pacific salmon should not be relied upon to describe those of fall Chinook salmon.

The Age-0 life history is dependent upon conditions that promote early emergence such that sufficient rearing, growth and energy reserves can be obtained before they migrate to the ocean. Migration must occur before summer temperatures become too warm. Warm fall and overwinter temperatures promote early emergence and the Age-0 life history. The primary historic spawning area of Snake River fall Chinook salmon was upstream of Swan Falls Dam (see Chandler 2007 for a review of historic conditions). This area is highly influenced by large volumes of spring flow into the Snake River that moderates fall and winter cooling and historically allowed for early emergence. Historically, the area below Hells Canyon Dam did not support a significant amount of spawning and was a cold over-winter environment, very similar to the Salmon River today. The moderated temperatures associated with construction of the HCC warmed fall and winter conditions and allowed continuation of the Age-0 life history. The habitat upstream of the HCC today is too degraded to support fall Chinook salmon (Groves and Chandler 2005). The Hells Canyon Reach of the Snake River, especially upstream of the Salmon River is the closest habitat available today to that of the historic environment that supported the Age-0 life history.

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[7] Consistent hatchery supplementation began in 1995 and has continued to the present. The numbers of hatchery reared juvenile fall Chinook salmon has ranged from 16,500 in 1995 to 6.5 million in 2009.

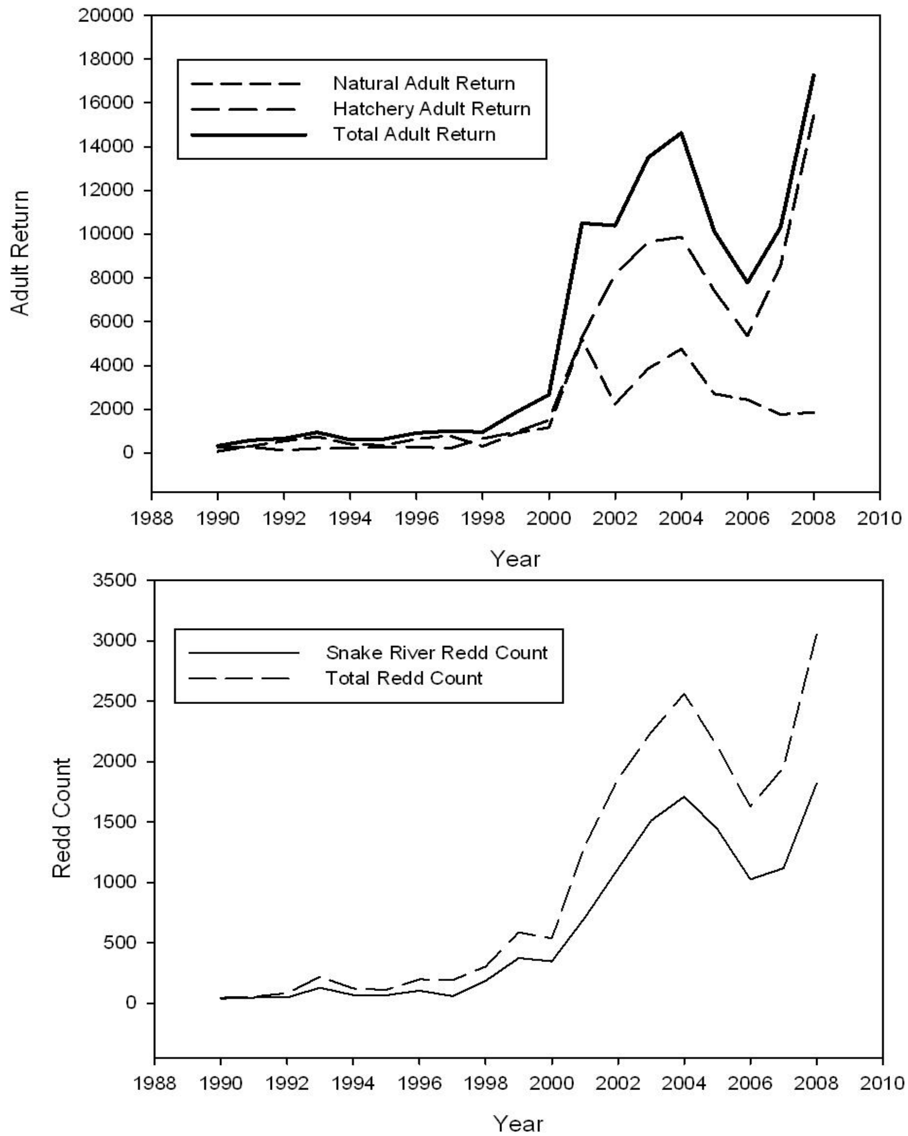

Figure 1. (*Top*) Hatchery and Natural Snake River adult returns (*Bottom*). Total redd counts and Snake River redd counts, 1990-2008. Total redd counts include all redds counted upstream of Lower Granite Dam which include the Snake, Grande Ronde, Clearwater, Imnaha and Salmon rivers (Source: Garcia et al. (2006) and IPC, USFWS, and the Nez Perce Tribe, unpublished information).

2.3. Existing Idaho and Oregon Water Quality Standards[8]

As noted, Idaho and Oregon have salmonid spawning temperature criteria applicable to the Snake River (Table 1). IDAPA 58.01. 02.286 and OAR 340-041-0028(4)(a). In addition, Oregon has species-specific and life-stage specific criteria.

Table 1. Idaho and Oregon salmonid spawning temperature criteria applicable to the Snake River below Hells Canyon Dam.

	Criteria	Spawning Period	Waters Protected
Idaho	Maximum Weekly Maximum of 13 °C	October 23 – April 15	Hells Canyon Dam to Salmon River confluence (RM 247.6 to RM 188.2)
Oregon	Seven-Day Average Maximum of 13 °C	October 23 – April 15	Hells Canyon Dam to the Salmon River confluence (RM 247.6 to RM 188.2)
Oregon	Seven-Day Average Maximum of 13 °C	November 1 through May 15	Salmon River confluence to the Oregon / Washington Border (RM 188.2 to RM 176.1)

Each state also has exclusions for natural conditions and air temperature. The natural conditions standards generally provide that should the IDEQ or ODEQ determine that the natural background temperatures exceed any biologically-based numeric criteria, that the natural background temperatures supersede the biologically-based criteria. IDAPA 58.01.02.053.04 and OAR 340-041-0028(8). Exceedences of biologically-based numeric temperature criteria that are attributable to maximum air temperatures that exceed the 90th percentile of a yearly series of temperatures specific to the State's criterion collected over specified periods of data are not violations of the standard. IDAPA 58.01.02.080.03. and OAR 340-041-0028(12)(c). Oregon's rules further provide that ~~t~~the seasonal thermal pattern in Columbia and Snake Rivers must reflect the natural seasonal thermal pattern." OAR 340-041-0028(4)(d). Each state also allows anthropogenic temperature increases. Oregon allows a cumulative increase of no more than 0.3 °C. OAR 340-041-0028(12)(b)(B). Idaho allows a similar increase applicable to point source wastewater receiving waters. IDAPA 58.01.02.401.03.a.v. The SR–HC-TMDLs established a salmonid spawning temperature target of a maximum weekly maximum temperature of 13 °C, or if the natural thermal potential is greater, an allowable cumulative increase of no more than 0.14 °C (IDEQ and ODEQ 2004).[9]

[8] Because the Snake River is boundary water and IPC seeks the development of consistent standards by each state, IPC references the applicable water quality standards of both Idaho and Oregon in this petition.

[9] Oregon has revised the anthropogenic temperature allowance standard to no more than 0.3 °C since the submission and the EPA approval of the SR–HC-TMDLs.

The IDEQ and ODEQ have interpreted the seven-day average maximum temperature to be the mean of daily maximum temperatures measured over a consecutive seven day period ending on the day of calculation. When used seasonally, as for spawning periods, the first applicable seven-day average occurs on the seventh day of the period. This interpretation is part of IDEQ water quality standards. IDAPA 58.01.02.010.52. The ODEQ has issued an Internal Management Directive with a similar calculation protocol (ODEQ 2008). Both follow the EPA recommended guidance (USEPA 2003). The salmonid spawning temperature criterion below the HCC starts on October 23 (Table 1). Applying the criterion in accordance with IDEQ and ODEQ interpretation and EPA's recommended guidance, the seven-day average maximum temperature is first calculated on October 29.

2.3.1. Snake River Fall Chinook Salmon Spawning Period

Idaho has identified a basin-specific period of October 23 through April 15 for fall Chinook salmon spawning and incubation for the mainstem Snake River from RM 188.2 (Salmon River confluence) to RM 247.6 ((Hells Canyon Dam; Table 1). IDAPA 58.01.02.286. Oregon has a basin-specific period of October 23 through April 15 for salmon and steelhead spawning through fry emergence for the mainstem Snake River from RM 188.2 to RM 247.6 consistent with Idaho, and also includes a period of November 1 through May 15 from RM 176.1 to RM 188.2. OAR 340-041-0028(4)(a) Figure 151B. OAR 340-041-0121. Table 121B only identifies the October 23 through April 15 salmon and steelhead through fry emergence period. The SR–HC-TMDLs, authored by both the IDEQ and ODEQ, utilized salmonid spawning criterion of a maximum weekly maximum no greater than 13°C that applies from October 23 through April 15 from Hell's Canyon Dam to the Salmon River (IDEQ and ODEQ 2004).

2.3.2. Snake River Fall Chinook Salmon Spawning Location

Idaho has identified waters of the Snake River that must support salmonid spawning (Table 1). IDAPA 58.01.02.130.01. Similarly, Oregon has identified a specific geographic location in which salmon and steelhead spawning through fry emergence must be protected for the mainstem Snake River. OAR 340-041-0028(4)(a) Figure 151B and OAR 340-041-0121 Table 121B. However, IPC believes the geographic extent identified in Table 121B is incorrect. Oregon identifies the Oregon/Washington border to be RM 169, which is actually near the confluence of the Grande Ronde River in Washington. The correct river mile for the Oregon/Washington border is RM 176.1. Additionally, OAR 340-041-0121 Table 121B sets a period of salmon and steelhead spawning through fry emergence different than Figure 151B. The SR–HC-TMDLs established that salmonid spawning must be protected in the Snake River from Hells Canyon Dam to the confluence with the Salmon River (IDEQ and ODEQ 2004).

2.4. Existing Conditions

Hydrology, inflowing warm water from sources upstream of the HCC, reservoir operations, and air temperatures all affect the magnitude and timing of seasonal warming and cooling in the Hells Canyon Reach. The SR–HC-TMDLs concluded that the hot, arid climate and non-quantifiable influences, such as upstream impoundments, upstream tributaries, water withdrawals, channel straightening, dikes, and removal of streamside vegetation, were the dominant causes of increased water temperatures in the Snake River (IDEQ and ODEQ 2004).

The HCC impoundments are uniquely located within a relatively narrow and steep-walled canyon. The HCC impoundments are not a heat source, but they do affect the timing of seasonal water temperatures exiting the Hells Canyon Dam. In the spring and summer, the HCC has an overall cooling effect on the downstream reach because, as upstream water temperatures increase, outflow from Hells Canyon Dam is composed of stored winter water, which remains cooler than the inflow to Brownlee Reservoir. This trend reverses in the fall as upstream water temperatures decline and outflow from the HCC is composed of stored spring and summer water, which is warmer than inflowing water. In addition, summer peak water temperatures in the outflow from Hells Canyon Dam are less than inflow, and base winter water temperatures in the outflow are warmer than the inflow.

A comparison of existing temperature conditions at Hells Canyon Dam in 1992, 1995, and 1997, which may be considered low, medium, and high flow (river discharge) years, respectively, to current salmonid spawning criteria show that Idaho's maximum weekly maximum criterion of no greater than 13 °C was exceeded in 1992 and 1995 and was equal to Idaho's maximum weekly maximum criterion plus allowable anthropogenic increase (i.e., 13.3 °C) in 1997 (Figure 2). While the calculation of a maximum weekly maximum temperature, by definition (IDAPA 58.01.02.52), is different than Oregon's seven-day average maximum temperature (OAR 340-041-0002(56)), attainment of the criteria, not to exceed 13 °C on the most critical consecutive seven-day period, are similar. Therefore, Oregon's seven-day average maximum (13.0 °C) was also exceeded in 1992 and 1995 (Figure 2). The magnitude and duration of numeric criterion exceedance varies by hydrologic and meteorological conditions among years as demonstrated by the years of 1991 to 2009 (Table 2).

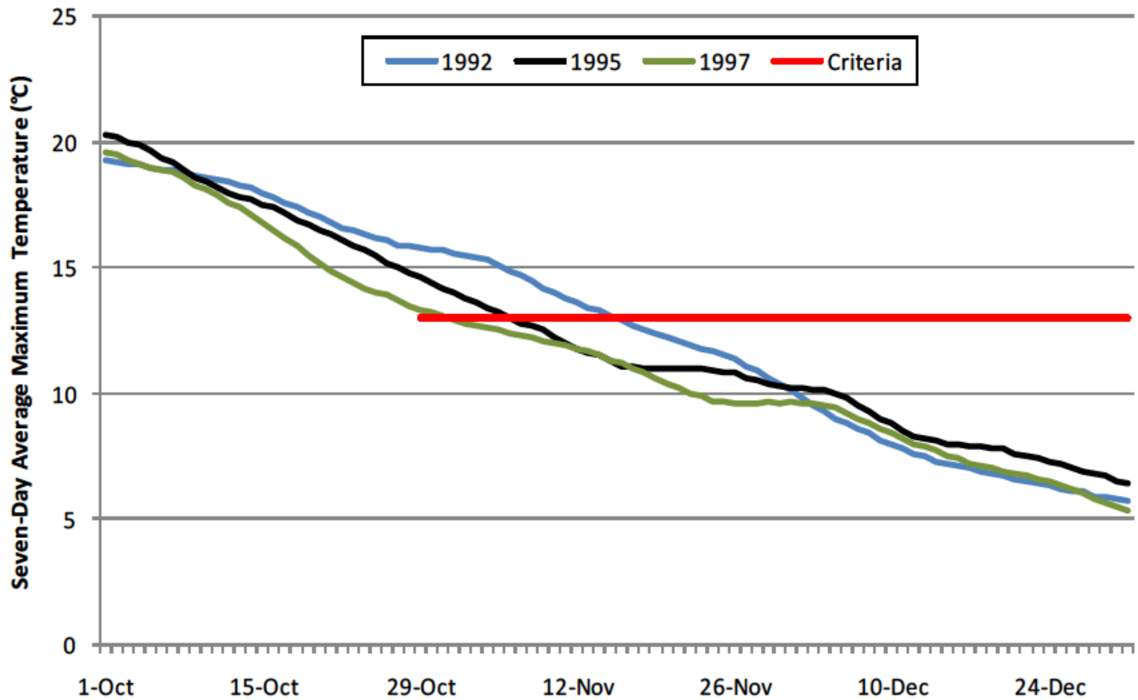

Figure 2. Snake River 7-day average maximum temperature at Hells Canyon Dam (RM 247.6) in 1992, 1995, and 1997 (calculated from October 23rd for a known result on October 29th) compared with maximum weekly maximum and 7-day average maximum criteria of 13.0 °C (existing criteria). These years may be considered representative of low, medium, and high flow years, respectively.

Table 2. Seven-day average maximum temperatures in degrees Celsius (°C) from 1991 through 2009 measured during the beginning of the designated salmonid spawning period for the Snake River at Hells Canyon Dam. Seven-day average maximum temperature is calculated as the daily maximum on a day and the six preceding days. NA indicates data were not available to calculate a seven-day average maximum temperature for that day.

	Seven-Day Average Maximum Temperature (°C)																		
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Oct 23																			
Oct 24																			
Oct 25																			
Oct 26																			
Oct 27																			
Oct 28																			
Oct 29	16.4	15.8	15.7	15.5	14.6	14.8	13.3	14.0	14.5	15.0	NA	15.3	16.8	16.3	15.7	15.3	14.5	14.9	14.8
Oct 30	16.1	15.7	15.6	15.4	14.4	14.5	13.2	13.9	14.4	14.8	NA	15.1	16.7	16.1	15.6	15.0	14.4	14.7	14.6
Oct 31	15.9	15.7	15.5	15.3	14.2	14.4	13.1	13.8	14.3	14.5	NA	14.9	16.5	15.9	15.5	14.8	14.2	14.5	14.4
Nov 1	15.6	15.6	15.4	15.1	14.0	14.2	12.9	13.7	14.1	14.3	NA	14.7	16.3	15.7	15.4	14.5	14.0	14.2	14.2
Nov 2	15.4	15.5	NA	15.0	13.8	14.0	12.8	13.5	14.0	14.1	NA	14.4	16.0	15.5	15.2	14.3	13.9	14.1	13.9
Nov 3	15.1	15.4	NA	14.8	13.6	13.9	12.7	13.4	13.8	14.0	NA	14.1	15.7	15.3	15.1	14.0	13.7	13.9	13.7
Nov 4	14.8	15.3	NA	14.6	13.4	13.7	12.6	13.2	13.6	13.8	NA	13.8	15.4	15.1	14.9	13.8	13.6	13.8	13.4
Nov 5	14.5	15.1	NA	14.3	13.2	13.4	12.5	13.0	13.4	13.7	NA	13.5	15.1	14.9	14.7	13.5	13.5	13.7	13.2
Nov 6	14.2	14.9	NA	14.1	13.0	13.2	12.4	12.8	13.2	13.5	NA	13.2	14.7	14.7	14.5	13.3	13.4	13.6	13.0
Nov 7	13.9	14.7	NA	13.9	12.8	12.9	12.3	12.6	13.0	13.3	NA	12.9	14.4	14.5	14.4	13.1	13.2	13.5	12.9
Nov 8	13.6	14.5	NA	13.7	12.7	12.7	12.2	12.5	12.9	13.2	NA	12.6	14.1	14.2	14.2	12.9	13.0	13.3	12.7
Nov 9	13.4	14.2	NA	13.5	12.5	12.4	12.1	12.4	12.7	13.0	NA	12.3	13.8	14.0	14.0	12.8	12.9	13.2	12.6
Nov 10	13.1	14.0	NA	13.3	12.2	12.2	12.0	12.3	12.6	12.8	NA	12.1	13.6	13.8	13.8	12.7	12.7	13.1	12.5
Nov 11	12.9	13.8	NA	13.1	12.0	11.9	11.9	12.2	12.5	12.7	NA	11.9	13.3	13.5	13.6	12.6	12.6	12.9	12.3
Nov 12	12.8	13.6	NA	12.9	11.8	11.7	11.8	12.1	12.4	12.5	NA	11.7	13.1	13.4	13.4	12.6	12.4	12.7	12.2
Nov 13	12.7	13.4	NA	12.7	11.6	11.5	11.7	12.1	12.3	12.2	NA	11.6	12.9	13.2	13.2	12.5	12.2	12.6	12.0
Nov 14	12.6	13.3	NA	12.5	11.5	11.3	11.5	12.0	12.2	12.1	NA	11.5	12.7	13.0	13.0	12.5	12.1	12.4	11.9

Water temperatures generally decline as one moves downstream of Hells Canyon Dam during the fall and early winter months providing inherent additional protection of the resource further downstream if criteria compliance was not achieved at Hells Canyon Dam (Figure 3). This is because the warmer stored water released from Hells Canyon Dam in the fall cools in the downstream reach to approach thermal equilibrium with stream heating and cooling processes. Julian day average seven-day average maximum temperatures (1991-2009; measured with Hydrolab at 10 minute intervals at HC Dam penstocks and with thermographs at hourly intervals at RM 192) were generally 0-0.5 °C cooler nearer the Salmon River confluence than immediately below Hells Canyon Dam. Further, the Snake River would not be warmed by Salmon River inflows as the seven-day average maximum temperature in the Salmon River is on average approximately 5.5 °C cooler than the Snake River above the confluence during the same period of record (Figure 4). IDEQ and ODEQ (2004) stated the Salmon River is without significant impoundments to store water and the watershed is sparsely populated and contains large portions in wilderness or roadless area. These attributes likely combine to make the Salmon River closer to the fall equilibrium than the Snake River below Hells Canyon Dam.

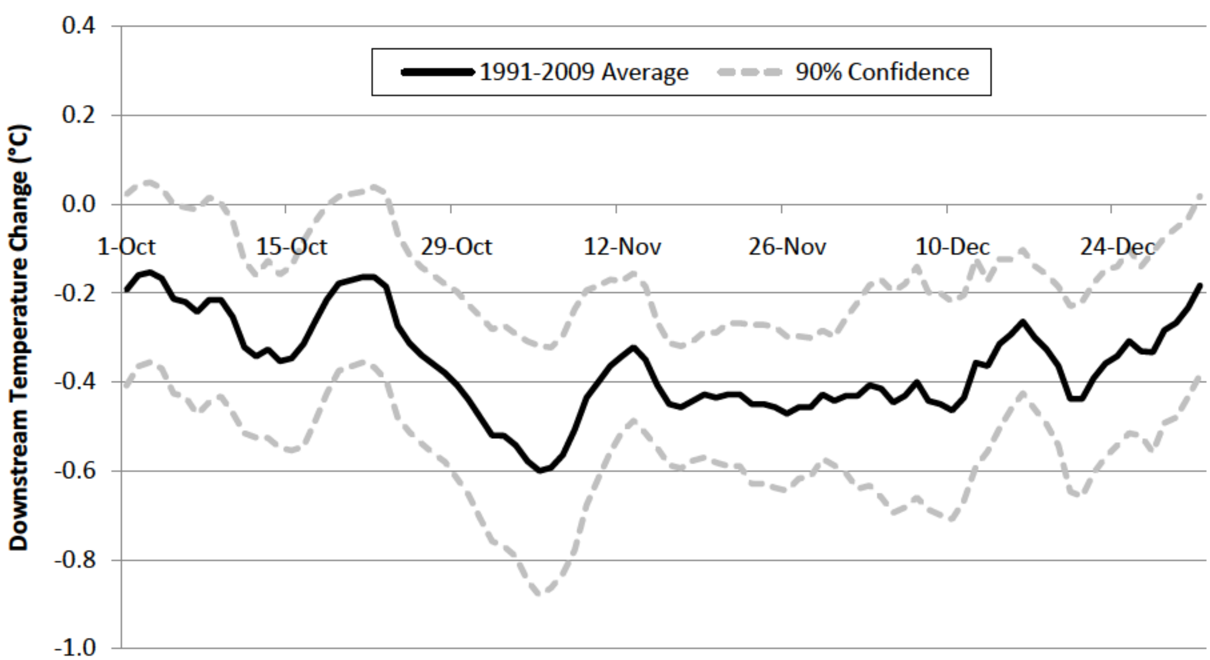

Figure 3. Summarized temperature differences from 1991-2009 between Hells Canyon Dam (RM 247.6) and just above the Salmon River confluence (RM 192). The temperature change represents the difference between the mean of the daily average for each Julian day between the two RM locations. Negative numbers indicate cooling. (Note: Data from all years were not available for all dates. Actual N for each day ranged from 12-15 for the 19 years.).

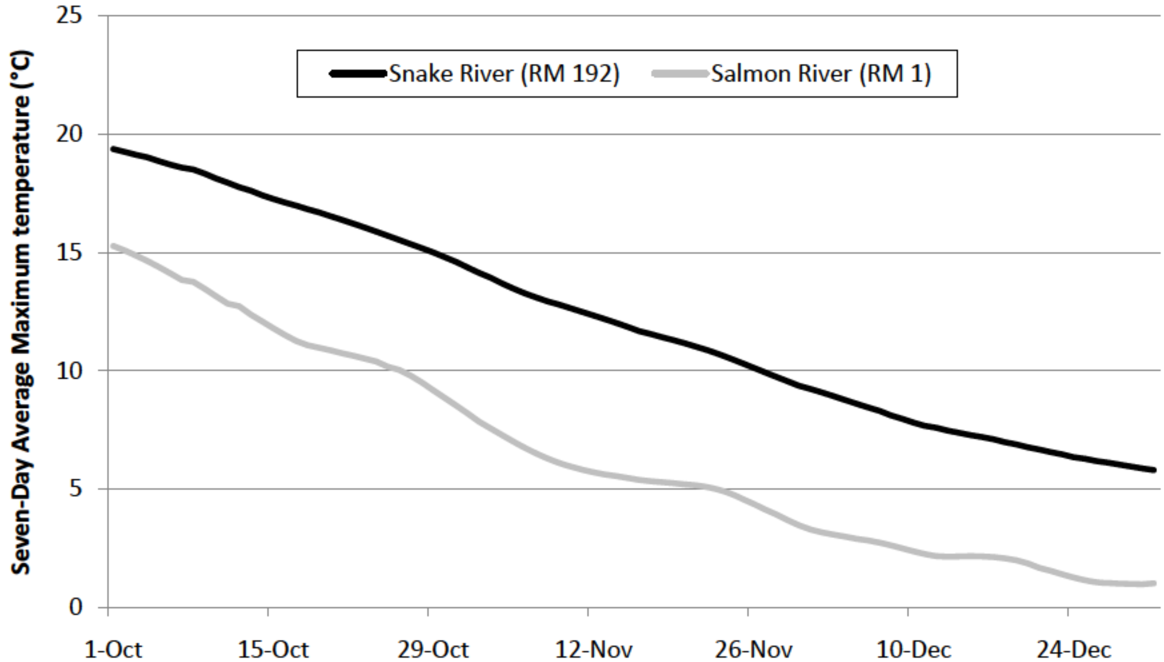

Figure 4. Julian Day seven-day average maximum temperatures of the Snake River (RM 192) just above the confluence with the Salmon River and the Salmon River (RM 1.5) recorded from 1991 through 2009.

3. Proposed Snake River Fall Chinook Salmon Site Specific Temperature Criteria

IPC proposes the following SSC in Idaho and Oregon that would be protective of Snake River fall Chinook salmon spawning.

Proposed Amendment to IDAPA 58.01.02

286. SNAKE RIVER, SUBSECTION 130.01, HUC 17060101, UNIT S1, S2, AND S3; SITE-SPECIFIC CRITERIA FOR WATER TEMPERATURE

A maximum weekly maximum temperature of fourteen and an half degrees C (14.5°C) applies from October 23rd through October 31st and a maximum weekly maximum of thirteen degrees C (13°C) applies from November 1st through April 15th to protect fall Chinook salmon spawning and incubation in the Snake River from Hell's Canyon Dam to the Salmon River.

Proposed Amendment to OAR 340-041-0028(4)

(g) The seven-day-average maximum temperature of a stream identified as having fall Chinook salmon spawning use may not exceed 14.5 degrees Celsius (58.1 degrees Fahrenheit) at the times indicated on Table 121B. The seven-day-average maximum temperature is a calculation of the average of the daily maximum temperatures from seven consecutive days made on a rolling basis.

Table 121B

BENEFICIAL USE DESIGNATIONS – FISH USES

MAINSTEM SNAKE RIVER

Geographic Extent of Use	Salmon and Steelhead Migration Corridors (20°C)	Redband or Lahontan Cutthroat Trout (20°C)	Fall Chinook Salmon Spawning (14.5°C)	Salmon and Steelhead Spawning through Fry Emergence (13°C)
Mainstem Snake River				
Oregon/Washington Border to Salmon River (RM 176.1 to RM 188.2)	X		October 23-October 31	November 1-May 15
Salmon River to Hells Canyon Dam (RM 188.2 to RM 247.6)	X		October 23-October 31	November 1-April 15
Hells Canyon Dam to Idaho Border (RM 247.6 to RM 409)		X		

4. RATIONALE FOR SNAKE RIVER FALL CHINOOK SALMON SPAWNING TEMPERATURE SITE SPECIFIC CRITERIA

A single salmonid spawning temperature criterion is not equally appropriate for all waters, for all species, or even for the entire spawning season in a single year. The current temperature criteria (13°C MWM or seven-day-average maximum) are based on available literature largely consisting of exposing incubating embryos to constant temperature regimes (see Davis 1975 and McCullough et al. 2001). However, thermal regimes in the natural environment are rarely constant and in the case of fall Chinook salmon and other fall spawning fish temperatures decline during spawning and early incubation. IPC seeks to establish a SSC that closely reflects the temperature requirements of the Snake River fall Chinook salmon during the spawning and early incubation stage.

Idaho regulations provide the Director with discretion to recognize that higher temperature criteria, that are protective of the beneficial uses, are appropriate in particular water bodies.

> **07. Temperature Criteria.** In the application of temperature criteria, the Director may, at his discretion, waive or raise the temperature criteria as they pertain to a specific water body. Any such determination shall be made consistent with 40 CFR 131.11 and shall be based on a finding that the designated aquatic life use is not an existing use in such water body or would be fully supported at a higher temperature criteria. For any determination, the Director shall, prior to making a determination, provide for public notice and comment on the proposed determination. For any such proposed determination, the Director shall prepare and make available to the public a technical support document addressing the proposed modification.

Hells Canyon reach, with its declining thermal regime in the fall, is just such a water body.

The EPA Region 10 Guidance (USEPA 2003) reflects the Agency's current analysis of temperature considerations for Pacific Northwest salmonid species. Specifically, it does not require strict compliance with the guidance; however, EPA intends to consider it when reviewing or promulgating temperature standards.

> ―…This guidance does not preclude States or Tribes from adopting temperature WQS different from those described. . . EPA would approve any temperature WQS that it determines are consistent with the applicable requirements of the CWA [protection and propagation of fish, shellfish, and wildlife] and its obligations under the ESA."[10]

The supporting science available at the time of the development of the EPA Region 10 Guidance (USEPA 2003) did not have the benefit of the more recent available literature demonstrating thermal requirements of incubating fall Chinook salmon (species and site specific information) and therefore the guidance is not as applicable to natural spawning of fall Chinook salmon as more recent published literature (e.g., Geist et al. 2006). Further, the guidance over-simplifies the complex issue of temperatures necessary to support designated beneficial uses (IPC 2002). Indeed, the guidance recognizes this by allowing the ability to adopt other temperature criteria that are protective.

4.1. Information Supportive of Fall Chinook Salmon Spawning Site Specific Temperature Criteria

4.1.1. Current Science Supporting Fall Chinook Salmon Site Specific Temperature Criteria

Numerous research studies report that temperatures greater than the current Oregon and Idaho salmonid spawning criteria of 13°C have comparable survival levels. Some of these studies are cited in the EPA Region 10 Guidance document. The most instructional research relative to SSC are those specific to fall

[10] NOAA Fisheries' response to the EPA Region 10 Guidance included a statement that while the guidance provides a good general overview, the Agency cannot pre-judge the effects of any proposed standard with respect to the Endangered Species Act or Essential Fish Habitat consultations. EPA and NOAA Fisheries expect to consult on each set of standards that EPA proposes to approve under the CWA.

Chinook salmon and those that evaluate naturally varying thermal regimes as opposed to constant thermal regimes (see Groves et al. 2007 for a complete review of 22 studies of temperature effects on incubation). Different species of Pacific salmon and even different races of Chinook salmon can differ substantially in their thermal tolerances and preferences (Beacham and Murray 1990, Beacham and Withler 1991).

The most pertinent studies for this proposal are those that simulated a naturally declining thermal regime for fall Chinook salmon. There are three such studies: Olson and Foster (1955), Olson et al. (1970) (which includes results of Olson and Nakatani (1968)), and Geist et al. (2006). Each study exposed newly spawned eggs to variants of a naturally declining thermal regime. The studies by Olson and Foster (1955) and Olson et al. (1970) were conducted using fall Chinook salmon from the Hanford Reach of the Columbia River, whereas the Geist et al. (2006) study used Snake River fall Chinook salmon. All three studies indicated a sharp increase in mortality when a threshold temperature during incubation was exceeded. Geist et al. (2006) reported a temperature threshold value of 16.5°C, where mortality began to sharply increase during incubation, whereas Olson and Foster (1955) study reported a value of 16.1°C. The Olson et al. (1970) did not report a threshold value, but rather looked at incremental temperature increases above the base Columbia River temperature during the fall Chinook salmon spawning period. The threshold increment above ambient river temperature at initial incubation yielded a temperature threshold for mortality similar to that found in the Olson and Foster (1955) report. Generally, the three studies are comparable, but have some differences that warrant consideration. The Geist et al. (2006) study used a 0.2°C daily rate of decline, which was comparable to data from the Snake River, whereas the Olson and Foster (1955) study used a daily rate of decline of 0.18°C. The Olson et al. (1970) study had a more variable rate of decline ranging from 1.1°C/d to 1.7°C/d (estimated from figures in the report) because they used Columbia River water at the existing temperatures as the baseline. The two Hanford Reach studies used Columbia River water, whereas the Geist et al. (2006) study used well water. The Hanford Reach studies monitored survival to a point past emergence whereas the Geist et al. (2006) monitored survival to emergence. Olson et al. (1970) was replicated over four spawning dates, whereas the Olson and Foster (1955) and the Geist et al. (2006) was conducted using one spawning date. These differences may be factors in the slightly higher threshold reported by Geist et al. (2006) than observed by Olson and Foster (1955). The three studies are similar enough, however, that a combined analysis of the three studies is warranted relative to the determination of a threshold value.

Using segmented regression analysis on the combined data, a spline model was created with two line segments. The point where the two lines come together is referred to as the join point, which could also be thought of as the threshold temperature where mortality begins to change. The join point from the combined data is estimated at 16°C, with 95% confidence intervals (CI) ranging from 15.3°C to 16.6°C (Figure 5).[11]

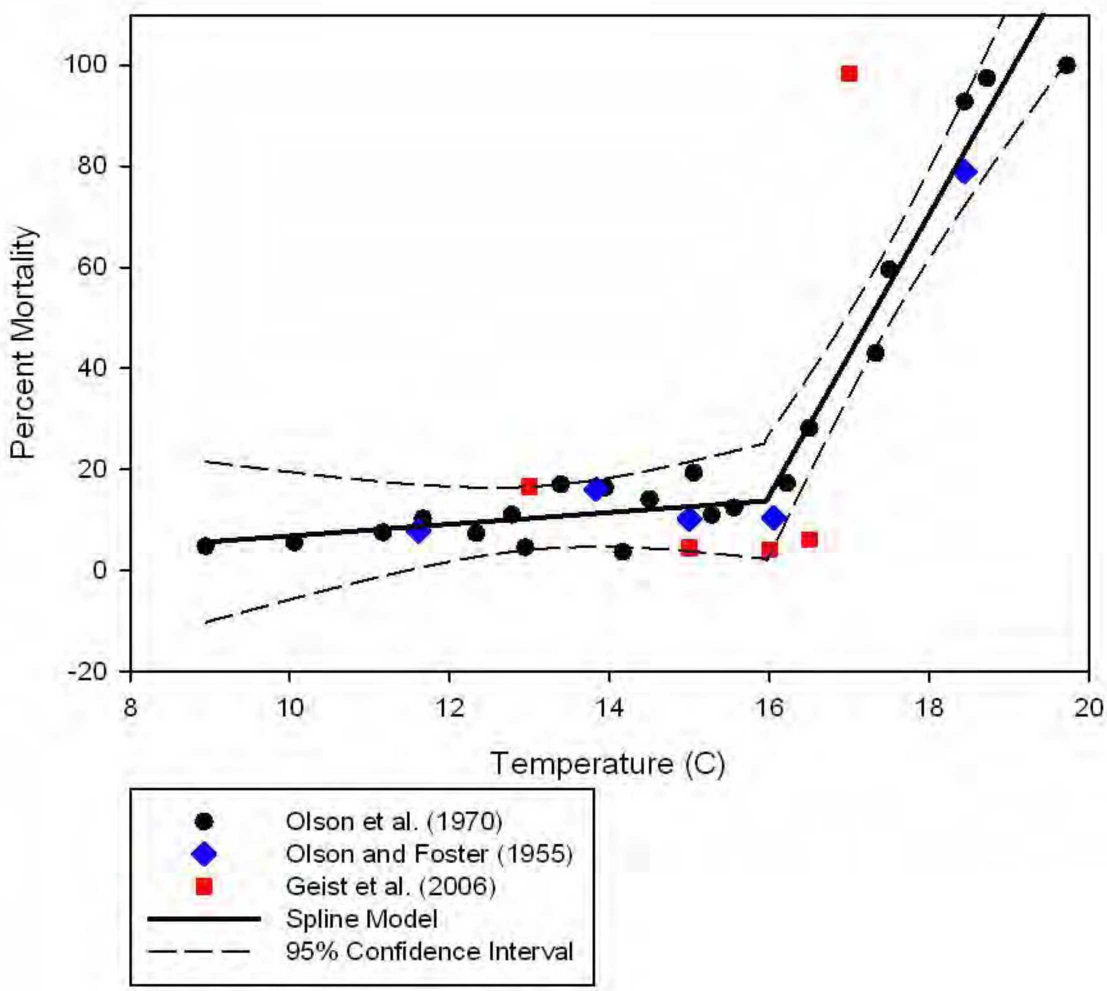

Figure 5. Combined data from three studies (Olson and Foster 1955, Olson et al. (1970) and Geist et al. (2006)) of fall Chinook salmon initial incubation temperatures and associated mortality to fry emergence under a declining thermal regime. Two line segments form a single spline model that estimates the join point (threshold value) of 16°C, with a 95% confidence interval ranging from 15.3°C to 16.6°C.

Below this temperature threshold, incubation mortality does not significantly differ (i.e., a line segment with a slope not significantly different from zero). Above the join point, mortality increases with a slope

[11] Data from the third spawning series in the Olson et al. (1970) report were excluded from the pooled study analysis consistent with the author's recommendations. Exclusion did not significantly affect the findings from the combined data analysis.

of 27.8 (i.e., mortality increases by this percentage with each 1°C increase in temperature). Using the estimated join point of 16°C as the initial incubation temperature and assuming a 0.2°C rate of daily cooling, the associated MWM would equal 15.4°C. Based on the 15.3°C (the lower 95% CI around the join point) as the most conservative initial incubation temperature where mortality would begin to increase with increasing temperature and the same assumed cooling rate, the associated MWM temperature would be 14.7°C (0.2°C greater than the proposed SSC).

4.1.2. Reasonable Assurance

Understanding thermal requirements of aquatic organisms invariably requires laboratory experiments where temperature can be isolated from other often confounding or synergistic factors. Many factors can influence the applicability of a laboratory study to a natural environment such as the Snake River. These can include flow through the redd environment, differences in redd temperatures relative to water column temperatures and potential synergies between DO levels, temperature and survival.

The Geist et al. (2006) study is especially relevant to temperature-oxygen relationships as they may affect a SSC for Snake River fall Chinook salmon. The study evaluated survival, development and growth of fall Chinook salmon embryos during the incubation period that were exposed to both variable temperature and DO regimes. This study allows an examination of potential synergies between temperatures and DO that might influence a SSC. The results showed that the mortality of incubating fall Chinook salmon exposed to variable temperature and DO conditions was not affected by DO levels as low as 4 mg O_2/L from initial temperatures of 15°C to 16.5°C, the temperature range at which DO was varied. Further, mean wet weight and mean fork length at emergence did not differ among any of the temperature and DO treatments. There are periods in the late summer and early fall when DO levels can be near 4 mg O_2/L in Hells Canyon, primarily in the upper portion of the Hells Canyon Reach. However, DO levels increase in the Hells Canyon Dam discharge during the fall months and increase even more with distance downstream as many of the larger rapids aerate the water. The SSC proposal of a Maximum Weekly Maximum of 14.5°C is within the variable temperature and DO ranges evaluated in the Geist et al. (2006) evaluation[12], and therefore it is reasonable to conclude that a synergistic affect relative to DO at levels as low as 4 mg O_2/L would not occur.

Another factor that could influence applicability of the lab study to the natural environment is the potential that temperatures experienced in the redd environment in some systems can differ from those in the surface water. Surface water can most readily be measured as the basis of determining compliance

[12] A MWM of 14.5°C would have an initial daily maximum temperature on October 23 of 15.1°C, assuming a 0.2°C/d rate of decline.

with state standards. Groves et al. (2008) compared temperatures within artificial redds and surface water and found no significant differences between the two environments in the Snake River. This is indicative that flow of surface water through the redd environment in the Snake River is relatively high, which allows for direct applicability of surface water temperatures when applying the lab study to the natural environment. This conclusion is also supported by DO levels and egg survival within artificial redds in the Hells Canyon Reach. The DO levels measured in artificial redds in the Hells Canyon Reach were consistently above 9 mg/l and generally < 2 mg/l different from the surface water, further suggesting high flow of surface water through the redd environment (see Chandler 2007 for a complete summary of artificial redd and egg survival in the Hells Canyon Reach).[13]

These findings suggest that the results of the referenced laboratory studies can reasonably be applied to the natural environment of the Snake River in the Hells Canyon Reach and provide reasonable assurance that this proposal for a MWM temperature of 14.5 °C during the October 23rd to October 29th time period is fully protective of fall Chinook salmon spawning and incubation. Reasonable assurance of beneficial use protection comes primarily from the combined data analysis discussed above (see Section 4.1.1; Figure 5). IPC has based its proposed SSC on the initial daily maximum temperature derived from statistical analysis of the combined data sets (the lower 95% CI around the join point). IPC's proposed SSC of a MWM temperature of 14.5 °C is indistinguishable, using the reported accuracy of temperature instrumentation of 0.2 °C, from the calculated MWM temperature of 14.7 °C that is associated with the initial daily maximum of 15.3 °C (the lower 95% CI around the join point) at similar rates of temperature decline. That is, the MWM of 14.7 °C would be considered the most conservative value that would define a threshold where mortality would begin to increase. Statistically, there is no difference in survival of fall Chinook salmon embryos through spawning and incubation starting at a daily maximum temperature of 15.1°C (MWM of 14.5°C) as compared to the current criteria of no initial daily maximum temperatures greater than 13.6 °C (MWM of 13°C). Additionally, IPC has illustrated (see Section 2.4; Figure 3) that temperatures decrease downstream of Hells Canyon Dam, further adding assurance that the proposed SSC monitored at the dam discharge will not be exceeded in the reaches where Chinook salmon spawn and incubate. This weight of evidence strongly supports a conclusion that IPC's proposed SSC provides reasonable assurance that the resource is protected.

4.2. A Comparison of Regional Fall Chinook Salmon Spawning Thermal Regimes

Evaluations of a declining temperature regime in the Columbia River demonstrate that healthy fall Chinook salmon populations initiate spawning at temperatures above 13 °C. Fall Chinook salmon begin

[13] No change in the DO standards are proposed in this SSC proposal.

spawning in October when ambient air and water temperatures are declining. Temperature at the initiation of fall Chinook salmon spawning in the natural environment is typically near 16 °C (Healey 1991). Exposure to higher temperatures is typically for short periods for small numbers of eggs at the beginning of the spawning season as the thermal regime begins to decline. For example, Chandler et al. (2001) estimated that 2% or less of redds are constructed below Hells Canyon Dam early enough for eggs to experience temperatures greater than 16 °C. Similar observation of fall Chinook salmon spawning above 16 °C have been reported for the Hanford Reach of the Columbia River (Dauble and Watson 1990) and for the lower Columbia River (Van der Naald et al. 2000).

The degree to which a beneficial use is being met in a particular location is often evaluated by comparing that location to a reference site or condition. Reference conditions should represent the best range of conditions or desirable conditions that can be achieved in similar waters in a particular ecological region. Reference conditions can be established using a combination of methods, including reference sites when known reference sites exist, historical data, paleoecological data, experimental laboratory data, quantitative models, and best professional judgment. Because there are few waters of similar watershed size, hydrologic characteristics, and similar biologic communities as the Snake River below the HCC, few comparable sites exist. The Hanford Reach of the Columbia River is the most comparable site. The Hanford Reach is considered an important production area for fall Chinook salmon; this stock of the most inland fall Chinook population is the most robust and healthy remaining in the Columbia River Basin and is not protected under the ESA (Huntington et al. 1996; Dauble and Watson 1997; Dauble and Geist 2000). The high level of fall Chinook salmon production in the Hanford Reach suggests that, among other conditions affecting beneficial use support, temperature-related conditions during immigration, spawning, and fry emergence are favorable for fully supporting an ocean-type life history.

IPC compared the thermal conditions and spawn timing of the Snake River below the HCC and the Hanford Reach of the Columbia River. Thermal data available for the Snake River included the years 1991-2003 (IPC unpublished information) and the years 1974-1992 for the Hanford Reach of the Columbia River (reported either from gaging station 12472900 located at Vernita Bar on the Columbia River or gaging station 12473520 located at Richland, Washington). The timing of spawning was compared using available data for the Hells Canyon Reach (1992 to 2002; IPC unpublished data) and available data for the Hanford Reach (1949 to 2002; provided from Battelle Memorial Pacific Northwest Laboratory, Richland Washington). Although initial spawning in the Hanford Reach was slightly earlier than the Hells Canyon Reach, the peak and final spawning times were not different (Table 3). The thermal regime of the Hanford Reach of the Columbia River and the Hells Canyon Reach upstream of the Salmon River are also very similar (Table 4). During the initiation of fall Chinook salmon spawning, the daily mean temperature of the Snake River upstream of the confluence with the Salmon River to the Hells Canyon Dam (14.7 °C) was not statistically different from that of the Hanford Reach (15.6 °C). Both were statistically warmer than the Snake River downstream of the confluence with the Salmon River (12.6 °C). Similar results were reported through peak spawning (occurring in early November). Both the upper Hells Canyon Reach and the Hanford Reach had daily mean temperatures of 12.5 °C at peak spawning.

Table 3. Julian date corresponding to specific spawning phases observed within the Hanford Reach of the Columbia River (HAN), and the lower and upper Snake River sub-reaches (LSR and USR, respectively). (Julian day 285 is 11 October; different letters within each row indicate significant differences at α=0.05.)

Spawning Phases	Julian date of occurrence within reaches		
	HAN	LSR	USR
Initial	289 $_{A}$	298 $_{B}$	297 $_{B}$
Peak	313 $_{A}$	312 $_{A}$	310 $_{A}$
Final	326 $_{A}$	330 $_{A}$	335 $_{A}$

Table 4. Mean water temperature (°C) present during specific spawning phases within the Hanford Reach of the Columbia River (HAN), and the lower and upper Snake River sub-reaches (LSR and USR, respectively). (Different letters within each row indicate significant differences at α=0.05.)

Spawning phases	Reach water temperature (°C)		
	HAN	LSR	USR
Initial	15.6 $_{B}$	12.6 $_{A}$	14.7 $_{B}$
7 days pre-initial	16.0 $_{B}$	13.5 $_{A}$	15.3 $_{B}$
Peak	12.5 $_{B}$	9.8 $_{A}$	12.5 $_{B}$
7 days pre-peak	12.9 $_{B}$	10.2 $_{A}$	13.0 $_{B}$
Final	10.5 $_{C}$	7.1 $_{A}$	8.7 $_{B}$
7 days pre-final	10.9 $_{C}$	7.6 $_{A}$	9.1 $_{B}$

A comparison of maximum weekly maximum temperatures (on October 29) was also made using recent information from the Hells Canyon Dam (RM 247.6), the Upper Hells Canyon Reach upstream of the Salmon River confluence (RM 192.3) the Lower Hells Canyon Reach downstream of the Grande Ronde

River (RM 165.7) and the Hanford Reach using provisional data available from the Grant County PUD from the tailrace of Priest Rapids Dam, the first dam on the Columbia River upstream of the Hanford Reach[14]. Data were available for 2006, 2008 and 2009. The comparison is consistent with the previous comparison, and demonstrates a very similar thermal regime between the Upper Hells Canyon Reach and the Hanford Reach (Table 5). Weekly Maximum temperatures on October 29 are the Maximum Weekly Maximum temperature during the designated fall Chinook salmonid spawning in the Snake River in the fall as temperatures decline.

Table 5. A comparison of the Weekly Maximum temperature (°C) on October 29th (i.e., from October 23) between the Hanford Reach of the Columbia River (as measured at Priest Rapids Dam tailrace), Hells Canyon Dam penstock, RM 192.3 (upstream of Salmon River confluence) and RM 165.7 (downstream of Grande Ronde River in lower Hells Canyon) for the years 2006, 2008 and 2009 (2007 data not available for Priest Rapids tailrace).

Year	Priest Rapids Tailrace	Hells Canyon Dam	RM 192.3	RM 165.7
2006	15.0	15.3	15	12.8
2008	14.3	14.9	14.8	12.6
2009	14.2	14.8	14.4	12.3

Several authors have estimated favorable ranges for large mainstem river Chinook salmon incubation including fall Chinook salmon. Boles et al. (1988) determined that initial spawning temperatures under a declining temperature regime could be as high as 15.5 °C for Sacramento River fall-run Chinook salmon. Bell (1986), as cited in Bjornn and Reiser (1991), estimated favorable incubation conditions for fall Chinook salmon to occur between 5.0–14.5 °C. Raleigh et al. (1986) recommended a range of between 6.0–14 °C. Comb and Burrows (1957) estimated upper temperature thresholds for incubation to occur between 14.2–15.5 °C. McCullough et al. (2001) suggested daily maximums during the incubation period not exceed 13.5–14.5 °C. The studies specific to declining thermal regimes for fall Chinook salmon suggest favorable upper initial temperatures as high as 16.1 to 16.5 (Olson et al. (1955); Geist et al. (2006)).

[14] (http://www.gcpud.org/resources/resLandWater/waterQuality.htm)

Higher initial incubation temperatures lead to shorter times to hatching and emergence, with resulting higher survival. Geist et al. (2006) showed that, as initial incubation temperature increased under a declining thermal regime, the time to hatching and emergence decreased. The inverse relationship between temperature and development time observed in that study is common among all salmon species (reviewed in Weatherly and Gill 1995). This earlier emergence has significant implications for Snake River fall Chinook salmon in the maintenance of an Age-0 life history. Survival of sub-yearling fall Chinook salmon that begin moving downstream the first week of July (after flows begin to decline and downstream reservoirs warm) survive at rates of only 5–20%, whereas those that initiate movement earlier in late May survive at rates of 65–90% (Connor et al. 2003; Smith et al. 2003). Many late emerging fall Chinook salmon, typical of the colder incubation thermal regime of the Clearwater River adopt an Age-1 life history, where they over-summer in the mainstem Snake and Columbia rivers before entering the ocean the following spring (Connor et al. 2002).

Because of the implications of earlier spawn timing relative to emergence timing, there is some thought that cooling river temperatures might promote earlier spawning and earlier emergence. Groves et al. (2007) compared initiation of spawning in the Upper Hells Canyon Reach (upstream of the Salmon River confluence), the Lower Hells Canyon Reach (downstream of the Salmon River confluence), and the Grande Ronde River (a Snake River tributary slightly downstream of the Salmon River confluence) based on weekly helicopter redd surveys since 1991. These systems all have different thermal regimes, with the Upper Hells Canyon Reach being the warmest. The three spawning stocks all follow the same route up the mainstem Snake River. Groves et al. (2007) concluded that there is no clear pattern of initiation of spawning and water temperature among these three nearby locations. Groves et al. (2007) also compared reports of spawn timing in the early 1950's (Zimmer 1950) upstream of the HCC site to spawn timing distribution today. Spawning was initiated in early October and extended over a relatively prolonged period through early December, with peak spawning occurring around the first week of November (Zimmer 1950). This is very similar to what has been observed today in the spawning area below Hells Canyon Dam. Thus, initiation of spawn timing does not seem strongly tied to a specific water temperature with the exception that as noted by Healey (1991) spawning generally commenced when temperatures begin to drop below 16ºC and that temperatures are on a declining limb associated with fall cooling..

4.3. Other Life Stage Considerations

The applicable aquatic life criterion for the state of Oregon for a stream identified as having a migration corridor use for salmon and steelhead is the seven-day average maximum temperature not to exceed 20.0 °C. OAR 340-041-0028(4)(d). This criterion is applicable to the Snake River from the Oregon/Washington border to Hells Canyon Dam (RM 176.1-247.6). In addition, there must be sufficiently distributed coldwater refugia to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body. Finally, the seasonal thermal pattern in Columbia and Snake Rivers must reflect the natural seasonal thermal pattern. For the state of Idaho, temperature limits for the protection of cold water aquatic life are a daily maximum not to exceed 22 ºC with a maximum daily average of no greater than 19 ºC. IDAPA 58.01.02.250.02.b..

Although the focus of this proposal is for a SSC specific to fall Chinook salmon spawning, some reviewers of the initial IPC proposal raised concerns over possible effects of an SSC on other life-stages of fall Chinook salmon due to the warmer fall environment associated with the HCC. One specific concern was that higher pre-spawn temperatures might influence spawning success because gametes may be less viable under warmer conditions. A similar concern is that warmer pre-spawn and initial spawn temperatures may be associated with a high pre-spawn mortality of adults or a delay in spawn timing. The aquatic life criteria identified for a migratory corridor of anadromous fish for Oregon and Idaho presumably was established to be protective of the pre-spawn environment. Other life stages of fall Chinook salmon have been reviewed for thermal limitations by Groves et al. (2007; Appendix 3). The findings from this review are summarized as follows:

- *Adult migration* – There has been no apparent shift in adult migration timing compared to the pre HCC environment. Adult fall Chinook salmon experience a similar period of exposure to temperatures elevated above 20 ºC between mid-August and mid-September as they did pre-HCC, but experience a lower maximum temperature than occurred historically. This is based on water temperatures present at Central Ferry in the early to mid-1950's, prior to construction of the HCC or the lower Snake River reservoirs.

- *Pre-spawn mortality* – Some level of pre-spawning mortality among anadromous salmonids is common. There is evidence that adult salmon in hatchery holding environments exposed to prolonged periods of water temperatures > 19 ºC could be subject to significant pre-spawn mortality. In hatchery holding situations, the mortality is usually associated with increased susceptibility to disease. However, fish-to-redd ratios documented in the Snake River do not suggest excessive pre-spawn mortality of fall Chinook salmon in the wild. Redd numbers relative to the total number of adult fall Chinook salmon allowed to pass upstream of Lower Granite Dam (with fallback and over-counting at the dam taken into account), the resulting fish to redd ratio has averaged 3.2 (range 2.0-4.2, data from 1993-2006). This comports well with (or better than) estimates of fish to redd ratios for the Hanford Reach of the Columbia River (3.0-16.0), where pre-spawn mortality is not considered to be a problem (Visser et al. 2002). It may be that the non-confined environment of a large river under a naturally declining thermal regime and the availability of cold water refugia make fish less susceptible to disease and mortality. In addition, the HCC has cooled late summer outflows relative to temperatures of the inflow. Also, the operations of Dworshak Reservoir on the Clearwater River release cold water in the summer that substantially cools portions of Lower Granite Reservoir, creating thermal refugia during the early pre-spawn environment. Thus, thermal conditions in the Snake River prevalent today are better (cooler) for pre-spawning adults than conditions prior to the HCC.

- *Gamete viability* – Studies cited to suggest reduced gamete viability as a result of prolonged exposure to warmer temperatures are not often relevant because they were not specifically designed to test this conjecture or because of the nature of the test exposures. For example, Jensen et al. (2006) did not hold adult Chinook salmon in a declining thermal regime typical of a riverine environment, but rather exemplified relatively long-term (40-days) exposure to elevated water temperatures. In addition, the control group held fish in a constant thermal environment of between 8 and 9 ºC, which cannot be compared to a declining thermal regime under more normative environments. Based on the available information, there is no evidence that the HCC has had an adverse effect on development of gametes in returning adult fall Chinook salmon.
- *Spawn timing* – There is no evidence that spawn timing has been greatly altered in the Snake River when comparing pre-HCC spawn distribution to that of the present-day Hells Canyon Reach spawn distribution.

5. SITE SPECIFIC CRITERIA WARRANTED

In summary, a SSC of 14.5°C Maximum Weekly Maximum is warranted for the Snake River downstream of the HCC to protect fall Chinook salmon spawning during the later part of October (October 23 through October 31) based on the body of scientific literature available and the thermal conditions observed in other fall Chinook salmon populations. Fall Chinook salmon spawn in lower elevation large mainstem rivers where warmer temperatures are prevalent. Initial spawning at temperature ≤ 16°C is common for fall Chinook salmon, even in systems other than the Snake River. The Age-0 life history is dependent upon conditions that promote early emergence. Warm fall and overwinter temperatures promote early emergence and the Age-0 life history. The Hells Canyon Reach of the Snake River, especially upstream of the Salmon River is the closest habitat available today to that of the historic environment and should be maintained. This proposed SSC protects and supports the beneficial use designated by both Idaho and Oregon and is more reflective of this large river environment and the life history of this fish.

6. SIGNATURE

For the reasons stated above, IPC respectfully submits this proposal to initiate the process to establish negotiated rulemaking for SSC for temperature as described in Section 2.1. herein.

IDAHO POWER COMPANY

Date: June 3, 2010

BY: ____________________________________

Title: Director, Environmental Affairs

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Appendix 1. Letter of concurrence by Dr. Charles C. Coutant that the proposed SSC is fully protective of fall Chinook salmon spawning and incubation based on best available scientific information.

Appendix 2. Letter of concurrence by Dr. Dudley W. Reiser that the proposed SSC is fully protective of fall Chinook salmon spawning and incubation based on the best available scientific information.

Appendix 3. Groves, P.A., J.A. Chandler, and R. Myers. 2007. White Paper: The effects of the Hells Canyon Complex relative to water temperature and fall chinook salmon. Idaho Power Company. Boise, Idaho.

Appendix 4. McCullough, D. 2007. “Review of Groves, Chandler, and Myers (2007)”, Columbia River Inter-Tribal Fish Commission. Portland. Oregon.

Appendix 5. Idaho Power Company. 2007. IPC's Evaluation of the Nez Perce Tribe's/CRITFC's Review of the Temperature White Paper.

Appendix 6. A Review of Comments by Dale A. McCullough (August 27, 2007) on white paper by Groves et al. (July 2007). Charles C. Coutant . June 8, 2010.

Charles C. Coutant, Ph. D.
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July 6, 2010

James A. Chandler
Fisheries Program Supervisor
Idaho Power Company
P.O. Box 70
Boise, ID 83707

Dear Mr. Chandler:

Ref.: Idaho Power Company's *Proposal to Initiate Negotiated Rule Making for Site Specific Temperature Criteria for Fall Chinook Salmon Spawning in the Hells Canyon Reach of the Snake River*

It is with pleasure that I write to concur with the July 2010 proposal by Idaho Power Company for site-specific water temperature criteria in autumn for Idaho and Oregon waters of the Snake River below the Hells Canyon project upstream of the confluence with the Salmon River. My concurrence is based on thorough reviews of the document draft and final, my reading of opposing views, my personal experience working with fall Chinook salmon in the Columbia River basin, and independent reviews I have conducted of the considerable relevant literature.

I was asked in mid-May to review the draft proposal to ensure that it was of high quality and scientifically defensible based on properly conveyed scientific and technical information. I also reviewed (1) a white paper produced by Idaho Power Company on temperature effects on fall Chinook salmon (prepared for FERC re-licensing, and broader in scope that the present proposal) that summarized relevant technical information, (2) a review of the white paper by the Nez Perce Tribe and CRITFC, and (3) a response to the Nez Perce/CRITFC review by Idaho Power Company. I provided technical comments and suggested edits on the draft proposal on June 8, 2010, along with my comments on the Nez Perce/CRITFC comments on the white paper. In addition, I provided a few detailed edits for the final draft to correct mainly typographical and style errors.

The well-prepared and documented proposal is clearly based on the best scientific information available in the peer-reviewed, published literature as well as relevant agency documents. On the basis of this information, it is my conclusion that the proposed site-specific standard of a weekly average of maximum daily temperatures of 14.5°C between October 23 and 31 will be protective of egg incubation for the fall Chinook salmon population in the Hells Canyon reach.

Sincerely,

Charles C. Coutant, Ph.D.

R2 Resource Consultants, Inc.

15250 NE 95th Street
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July 8, 2010

Mr. Jim Chandler
Idaho Power Company
Post Office Box 70
Boise, Idaho 83707

Subject: Review and analysis of IPC's Proposal to Initiate Negotiated Rule Making for Site Specific Temperature Criteria for Fall Chinook Salmon Spawning in the Hells Canyon Reach of the Snake River

Dear Mr. Chandler:

Per your request of May 19, 2010, I have completed an independent review of Idaho Power Company's (IPC) proposal related to site specific temperature criteria for fall Chinook salmon spawning in the Hells Canyon Reach (HCR) of the Snake River. This letter contains my conclusions regarding the proposal. My review focused on the extent and relevance of the technical documents and data presented in the proposal, and whether in my opinion they formed an appropriate and sufficient information base from which the proposed criteria could be logically derived, and further, whether in my opinion the criteria as proposed would be protective of fall Chinook salmon spawning in the HCR of the Snake River.

As part of this process, I reviewed the following background materials provided by IPC:

- Groves, P.A., J.A. Chandler, and R. Myers. 2007. White Paper. The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon. Final Report, Hells Canyon Complex, FERC No. 1971. July 2007.
- McCullough, D.A. 2007. Review of: Groves, P.A., J.A. Chandler, and R. Myers. 2007. White Paper. The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon. Final Report, Hells Canyon Complex, FERC No. 1971. July 2007; Review for Columbia River Inter-tribal Fish Commission.
- Idaho Power Company. 2008. Response to Nez Perce/CRITFC Review of Temperature White Paper. Transmitted via J. Tucker letter May 2, 2008.
- Groves, P.A., J.A. Chandler, and T.J. Richter. 2008. Comparison of temperature data collected from artificial Chinook salmon redds and surface water in the Snake River. North American Journal of Fisheries Management 28:766-780.
- Geist, D.R., C. S. Abernathy, K.D. Hand, V.I. Cullinan, J.A. Chandler, and P.A. Groves. 2006. Survival, development, and growth of fall Chinook salmon embryos, alevin, and fry exposed to variable thermal and dissolved oxygen regimes. Transaction of the American Fisheries Society 135:1462-1477.

I also compiled and reviewed a number of other technical publications that were directly related or relevant to the Hells Canyon Reach of the Snake River including:

- Groves, P.A., J.A. Chandler, and T.J. Richter. 2008. Comparison of temperature data collected from artificial Chinook salmon redds and surface water in the Snake River. North American Journal of Fisheries Management. 28:766-780.
- Connor, W.P., H. Burge, R. Waitt, and T.C. Bjornn. 2002. Juvenile life history of wild fall Chinook salmon in the Snake and Clearwater rivers. North American Journal of Fisheries Management. 22:703-712.
- Connor, W.P., H. Burge, and D.H. Bennett. 1998. Detection of PIT-tagged subyearling Chinook salmon at a Snake River Dam: Implications for summer flow augmentation. North American Journal of Fisheries Management. 18:530-536.
- Groves, P.A. and J.A. Chandler. 1999. Spawning habitat used by fall Chinook salmon in the Snake River. North American Journal of Fisheries Management. 19:912-922.
- Keefer, M.L., C. Peery, T.C. Bjornn, M. Jepson, and L. Stuehrenberg. 2004. Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake rivers. Transactions of the American Fisheries Society. 133: 1413-1439.
- Connor, W.P. and H. Burge. 2003. Growth of wild subyearling fall Chinook salmon in the Snake River. North American Journal of Fisheries Management. 23:594-599.
- McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids with special reference to chinook salmon. Columbia River Inter-Tribal Fish Commission. Prepared for U.S. Environmental Protection Agency, Seattle, Washington. 279 pp.

The above documents and literature provided additional context from which to complete my review of the proposal.

My overall review of the collective information indicates that IPC has conducted a thorough evaluation of both published and unpublished literature and data relevant to the issue of water temperature effects on the ecology and life history requirements of fall Chinook salmon, in particular the effects related to spawning and egg incubation, as well as fry survival and to some degree growth. The summary document of Groves et al. (2007) provided a thorough synopsis and review of temperature related information pertaining to various fall Chinook life stage thermal requirements and tolerances, and did so relative to both current and estimated historical temperature regimes of the Snake River. In many ways, it complements the broader work completed by McCullough (1999) that focused more on an overall evaluation of thermal requirements of salmonids with a focus on Chinook. The work of Groves et al. (2007) included a detailed assessment of data specific to the Hells Canyon Complex and other systems on the Snake River (e.g., Lower Granite, etc.), and importantly and in addition, compiling and considering information from the Hanford Reach of the Columbia River, a system that currently supports a healthy, sustainable population of fall Chinook salmon. Perhaps most importantly, the detailed laboratory analysis conducted by Battelle that was funded by IPC specifically evaluated the effects of varying water temperatures on fall Chinook salmon egg incubation, fry survival, and growth. The results of that study were subsequently published by Geist et al. (2006) and demonstrated that egg survival was not negatively affected by temperatures up to 16.5°C. Overall, the documents cited and considered in the development of the proposal represent both contemporary and key foundational literature relevant to salmonid temperature requirements. When coupled with information specific to the Hells Canyon Reach of the Snake River, it is clear that IPC had compiled and reviewed all of what I would consider the major keystone pieces of information related to salmonid temperature requirements and that the amount of literature was more than sufficient for developing the proposed site specific criteria. Thus, my first conclusion related to the proposal is that the information and data assembled were appropriate and sufficient for developing the site specific criteria proposal.

My review of the actual proposal indicates that substantial thought and consideration went into its derivation including an effort to reconstruct the temperature regime that fall Chinook populations in the Snake River were historically subjected to in reaches they inhabited upstream from the current Hells Canyon Dam, and that are currently influenced by both Swan Falls and Brownlee dams. The analysis supported the argument raised by IPC that with the construction of these two dams, the temperature regime has been essentially reset to a lower reach in the system. This means that temperatures that fall Chinook were historically subjected to in the Snake River that occurred in areas proximal to the Swan Falls reach are now generally provided in the Hells Canyon Reach. My review also noted that IPC had submitted an earlier proposal for temperature criteria that had a higher temperature threshold than the current proposal; 16.5°C vs. 14.5°C. IPC received a number of substantial and useful comments on that proposal, in particular those of McCullough (2007) of the Columbia River Inter-Tribal Fish Commission. Although the comments addressed a number of life stage elements of the reproductive phase of the Chinook life cycle, the general theme of the comments relative to Chinook spawning and egg incubation was that a temperature criteria set at 16.5°C was too close to published threshold temperature values that have been found to be detrimental to embryo survival. IPC in their revised proposal apparently considered these comments, and has appropriately modified the proposal to the 14.5°C criteria inclusive of the primary spawning period of fall Chinook salmon (from October 23 to October 30), with a further reduction to 13°C from November 1 through May 15. This reduction of the initial temperature criteria should decrease the risk (compared to the 16.5°C threshold) of thermal impacts to spawning and egg incubation of fall Chinook during the early periods of spawning. However, review of the proposal indicates that even with this criterion, IPC's existing operations will likely need to be adjusted in order for IPC to meet the early (October 23-October 30) criterion. With this consideration in mind, it is my opinion that the proposed SSC would be protective of fall Chinook salmon spawning, egg incubation, and fry emergence.

Please do not hesitate to contact me should you have any questions.

Sincerely,

Dudley W. Reiser, Ph.D.
Senior Fish Scientist

DWR/sp
LN583.doc

White Paper:

The Effects of the Hells Canyon Complex Relative to Water Temperature and Fall Chinook Salmon.

Phillip A. Groves
James A. Chandler
Ralph Myers

Final Report

Hells Canyon Complex
FERC No. 1971

July 2007

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Executive Summary

Several stakeholders interested in the relicensing by the Federal Energy Regulatory Commission (FERC) of the Hells Canyon Complex (HCC) have expressed concern over perceived downstream temperature impacts on fall Chinook salmon. For example, comments filed on FERC's draft environmental impact statement by the Environmental Protection Agency and others assert that the thermal shift associated with the HCC is deleterious to salmon at different life stages. The comments argue that installation of a temperature control structure in Brownlee Reservoir could ameliorate the hypothesized negative effects associated with this thermal shift by providing cooler conditions below the HCC in July and in the early fall, and therefore, FERC should require more investigation.

The temperature effects of the HCC are documented in the FERC License Application and in the application for certification under Clean Water Act § 401 filed before the Oregon and Idaho Departments of Environmental Quality. However, in response to the comments submitted to FERC, Idaho Power Company has prepared this White Paper, which comprehensively reviews and analyses HCC temperature effects against the literature and its own data gathered over many years. Our conclusion, based on the best available science, is that the temperature effects of the HCC are benign or beneficial to fall Chinook salmon. Specifically, the White Paper finds:

1. Significant anthropogenic influences on water temperature have occurred in the Snake River basin both upstream of Hells Canyon Dam and as a result of the Hells Canyon Complex. Generally, temperatures upstream of the Hells Canyon Complex are warmer during the spring and summer months relative to the pre-development era (pre-1860). This thermal inertia influences the magnitude and duration of the thermal shift downstream of Hells Canyon Dam that was created by the operation of the HCC.

2. The presence of the HCC has also created warmer over-winter base temperatures in the area below Hells Canyon Dam relative to the pre-development era because of the large volume of 4ºC water stored in Brownlee Reservoir over the winter months.

3. The primary effect of this altered thermal regime to the various life stages are as follows:

   a. *Adult migration* – There has been no apparent shift in adult migration timing. Adult fall Chinook salmon experience a similar period of exposure to temperatures elevated above 20 ºC between mid-August and mid-September as they did pre-HCC, but experience a lower maximum temperature than occurred historically. This is based on water temperatures present at Central Ferry in the early to mid-1950's, prior to construction of the HCC or the lower Snake River reservoirs.

b. *Pre-spawn mortality* – Some level of pre-spawning mortality among anadromous salmonids is common. There is evidence that adult salmon in hatchery holding environments exposed to prolonged periods of water temperatures > 19 ºC could be subject to significant pre-spawn mortality. In hatchery holding situations, the mortality is usually associated with increased susceptibility to disease. However, fish-to-redd ratios documented in the Snake River do not suggest excessive pre-spawn mortality of fall Chinook salmon. It may be that the non-confined environment of a large river under a naturally declining thermal regime and the availability of cooler refuge makes fish less susceptible to disease and mortality. In addition, the HCC has cooled late summer outflows relative to levels associated with the inflow temperature and the operations of Dworshak Reservoir substantially cool areas associated with Lower Granite Reservoir and create thermal refugia during the early pre-spawn environment such that conditions prevalent today are better than conditions prior to the HCC.

c. *Gamete viability* – A through review of the literature demonstrates that studies often cited to suggest reduced gamete viability as a result of prolonged exposure to warmer temperatures should not be cited as supporting literature. The studies typically were not designed to address the question. One study that could be cited as supporting evidence (Jensen et al. 2006) did not hold adult Chinook salmon in a declining thermal regime typical of a riverine environment, but rather exemplified relatively long-term (40-days) exposure to elevated water temperatures. In addition, the control group held fish in a constant thermal environment of between 8 and 9 ºC, which cannot be compared to a declining thermal regime under more normative environments. Based on the available information, it is difficult to conclude that the HCC has had an adverse effect on development of gametes in returning adult fall Chinook salmon.

d. *Disease susceptibility* – Similar to the findings discussed under pre-spawn mortality, adults held in confined hatchery environments under prolonged periods of elevated temperature appear to have a greater susceptibility to disease or fungal infections. How this pertains to free-ranging adults is uncertain. However as discussed above, fish-to-redd ratios do not suggest a high level of pre-spawn mortality below Hells Canyon Dam.

e. *Spawn timing* – There is no evidence that spawn timing has been greatly altered in the Snake River when comparing pre-HCC spawn distribution to that of the present-day Hells Canyon spawn distribution.

f. *Incubation Survival* – Experiments based on constant and declining thermal regimes differ markedly in their results with respect to both ultimate survival and size of fry at emergence. To assess the thermal requirements of incubating eggs in a natural declining thermal regime, Olson and Foster (1955), Olson et al. (1970) and Geist et al. (2006) are the most applicable findings to conditions experienced by Snake River fall Chinook salmon. These studies suggest that eggs spawned at initial temperatures of between 16 ºC to16.5 ºC do not experience different levels of mortality from those eggs spawned at temperatures as low as 13 ºC. At temperatures above 16.5 ºC, mortality of incubating embryos substantially increases. The thermal shift that occurs below Hells Canyon Dam delays cooling of water temperature in the fall and significantly advances the emergence timing of juvenile fall Chinook salmon closer to what occurred historically in the primary production areas upstream of the Hells Canyon Complex. The HCC is now more suitable for the expression of an Age-0 fall Chinook salmon life history than it was before construction of the HCC. The elevated winter base temperatures also contribute to the advanced emergence timing relative to pre-HCC.

g. *Effects of intragravel water temperature* – In Hells Canyon, there is a strong connection between the water column and the redd environment that allows for similar thermal conditions between the two environments. Therefore, the water column conditions provide good metrics for describing the thermal conditions of incubating embryos in Hells Canyon.

h. *Emergence / Outmigration Timing* - Fall Chinook salmon emerge earlier today in Hells Canyon than they did historically in Hells Canyon because of the warmer incubation conditions present today as a result of the HCC. Historically, Hells Canyon was a very cold environment and may not have been conducive for production of an Age-0 migrating fall Chinook salmon. The construction of the HCC altered the thermal regime such that emergence timing is now closer to what occurred historically in the production areas upstream of the HCC. During the 1990's, there was evidence that juvenile outmigration was delayed based on their arrival timing at Lower Granite Dam. Migration through the large slack water environment of Lower Granite Reservoir is more likely to explain the delay observed during that time. Recently, there is evidence of an earlier shift in the outmigration timing at Lower Granite. Fall Chinook salmon appear to be migrating earlier and at a smaller size than observed in the 1990's. Why this trend is occurring is uncertain, but may relate in some way to density in the rearing areas as adult returns and natural production has continued to increase.

1. Introduction

The purpose of this white paper is to consolidate information relative to water temperature and fall Chinook salmon below Hells Canyon Dam. The paper reviews applicable water quality criteria for the Snake River for fall Chinook salmon. It reviews the anthropogenic influences in the Snake River. Significant anthropogenic influences on water temperature have occurred in the Snake River basin both upstream of Hells Canyon Dam and as a result of the Hells Canyon Complex. Generally, upstream of the Hells Canyon Complex is warmer during the spring and summer months relative to the pre-development era (pre-1860). This thermal inertia influences the magnitude and duration of the thermal shift downstream of Hells Canyon Dam that was created by the operation of the HCC. This paper discusses what the effect of those changes are to fall Chinook salmon life-stages dependent upon the habitats below Hells Canyon Dam today.

2. Review of Temperature Criteria for the Snake River

For purposes of this report, the temperature criteria assessment for the Snake River was limited to the stretch of the river forming the border between Idaho and Oregon (RM 409 – 169). Application of temperature standards in Oregon and Idaho is similar. Both states have five types of temperature standards: 1) biologically-based criteria that ensure thermally optimal conditions; 2) natural conditions (as determined by the states), which supersede biologically-based criteria; 3) air temperature exclusion criteria that allow for exceedence of numeric and natural conditions; 4) human use allowance, which allow insignificant additions of heat due to anthropogenic sources; and 5) site-specific criteria, requiring water-body specific rulemaking that is based on the unique characteristics of the watershed (IDAPA 58.01.02. n.d., OAR 340-041 n.d.). Temperature criteria are applicable to specified locales and times depending on the species and activities that are present. Additionally, Oregon standards require that the seasonal thermal pattern in the Snake River must reflect the natural seasonal thermal pattern (OAR 340-041-0028(4)(d)). The purpose of temperature criteria is to protect designated temperature-sensitive beneficial uses, including specific salmonid life cycle stages, when and where those uses occur.

While both Oregon and Idaho similarly apply temperature standards, the biologically-based criteria differ. The SR-HC TMDL established the most conservative criteria as the targets for attainment of water quality standards and protection of designated beneficial uses (IDEQ and ODEQ 2004). Both Oregon and Idaho have since revised their water quality standards, including the temperature standards. IPC presented these changes in its revised § 401 certification application, where appropriate, and attempted to identify the most conservative criteria to be consistent with the approach used in the SR-HC TMDL.

2.1 Aquatic Life and Salmonid Rearing

The aquatic life beneficial use classifications are for waters that are suitable or intended to be made suitable for protection and maintenance of viable communities of aquatic organisms of significant aquatic species (IDEQ and ODEQ 2004). Resident and anadromous salmonids exist in the HCC and Snake River, and the applicable biologically-based criteria are dependent on their distribution. Resident salmonids, particularly redband trout, exist upstream of Hells Canyon Dam. Anadromous fall Chinook salmon and steelhead inhabit the Snake River downstream of Hells Canyon Dam. Significant viable populations of cool and warm water aquatic species exist in the HCC reservoirs. These include predominantly smallmouth bass (*Micropterus dolomieui*), black crappie (*Pomoxis nigromaculatus*), and white crappie (*P. annularis*) (Richter and Chandler 2003).

The SR-HC TMDL evaluation of Oregon and Idaho water quality standards, as first published in 2003, identified as most conservative the then existing Oregon numeric temperature criterion for salmonid rearing of a seven-day average maximum temperature of 17.8 °C (IDEQ and ODEQ 2004). Therefore, the SR-HC TMDL temperature target was established at this criterion to be applied year round to the HCC reservoirs and outflows with June to September as the critical time period.[1] Oregon has since revised its water quality standards, including temperature standards. Oregon currently has two temperature criteria applicable to waters of the HCC and Snake River.

- The seven-day average maximum temperature of a stream identified as having Lahontan cutthroat trout or redband trout use may not exceed 20.0 °C (OAR 340-041-0028(4)(e)). This criterion is applicable to the HCC reservoirs and Snake River from RM 247.5 to RM 409.

- The seven-day average maximum temperature of a stream identified as having a migration corridor use for salmon and steelhead may not exceed 20.0 °C (OAR 340-041-0028(4)(d)). This criterion is applicable to the Snake River from RM 169 to RM 247.5. In addition, there must be sufficiently distributed coldwater refugia to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body. Finally, the seasonal thermal pattern in Columbia and Snake Rivers must reflect the natural seasonal thermal pattern.

Idaho temperature criteria for the protection of cold water aquatic life are a daily maximum not to exceed 22 ºC with a maximum daily average of no greater than 19 ºC (IDAPA 58.01.02.250.02.b.). IPC believes Oregon's temperature criteria are still more conservative than Idaho's and its revised § 401 certification application evaluated

[1] There are two exceptions. The numeric criterion does not apply when the temperature in excess is naturally occurring or when the daily maximum air temperature exceeds the 90th percentile of the seven-day average daily maximum air temperature calculated over a ten-year period.

conditions relative to standards using Oregon’s seven-day average maximum criteria of 20 °C applied year round in the HCC reservoirs and outflows.

2.2 Salmonid Spawning

Oregon and Idaho have criteria to protect spawning salmonids in areas and during times the species are present. The SR-HC TMDL stated that water quality standards for salmonid spawning would apply only to that portion of the Snake River below Hells Canyon Dam (RM 247 to 188) from October 23 through April 15 for fall Chinook salmon and November 1 through March 30 for mountain whitefish (IDEQ and ODEQ 2004). The SR-HC TMDL used Idaho’s criterion, which is a maximum weekly maximum temperature of 13.0 °C (IDAPA 58.01.02.286.).

Oregon’s salmon and steelhead spawning temperature criterion is a seven-day average maximum temperature not to exceed 13.0 °C (OAR 340-041-0028(4)(a)). This criterion is applicable to the Snake River from RM 188 to RM 247.5 from October 23 through April 15 and from RM 169 to RM 188 from November 1 through May 15. In addition, Oregon has revised the human use allowance standard (OAR 340-041-0028(12)(b)) to include a cumulative increase from anthropogenic sources of no more than 0.3 °C above the applicable criteria. Idaho criteria apply in the Snake River downstream of Hells Canyon Dam to the confluence with the Salmon River; RM 188-247.5. Specifically, a maximum weekly maximum temperature of 13 °C applies from October 23 through April 15 (IDAPA 58.01.02.286).

Consistent with the SR-HC TMDL, IPC attempted to evaluate conditions relative to the most conservative standard in either Oregon or Idaho. While the Idaho calculation of a maximum weekly maximum temperature (IDAPA 58.01.02.010.55) is different than the Oregon seven-day average maximum temperature (OAR 340-041-0002(54)), IPC believes the objectives of both criteria, not to exceed 13 ºC on the most critical consecutive seven-day period, are similar. Therefore, IPC evaluated data, in relation to salmonid spawning, against a seven-day average maximum not to exceed 13 ºC.

The IDEQ and ODEQ have interpreted the seven-day average maximum temperature to be the mean of daily maximum temperatures measured over a consecutive seven day period ending on the day of calculation. This interpretation is part of an Idaho proposed rule change (IDEQ 2006) and an Internal Management Directive being drafted by Oregon (ODEQ 2006). Both follow EPA’s recommended guidance (USEPA 2003).The salmonid spawning temperature criterion below the HCC starts on October 23. Applying the criterion in accordance with the IDEQ and ODEQ interpretation, the seven-day average maximum temperature is first calculated on October 29.

3. Influence of Anthropogenic activities upstream of HCC

3.1 Estimated Historic Temperature

Water quality in Hells Canyon reservoirs and releases from the Hells Canyon Complex is a function inflowing water quality as well as in-reservoir processes. Instantaneous temperatures greater than the 20 ºC criterion for cold water biota have been documented to likely occur in all years in both the HCC reservoirs and releases (IPC 2007). Likewise, temperatures greater than the seven-day average maximum temperature criterion of 13 ºC for salmonid spawning occur in most years. The elevated temperatures that exceed the criterion occur during the first few weeks of the fall Chinook salmon spawning season.

In addition to numeric criteria, Oregon has a narrative temperature standard applicable to the Snake and Columbia Rivers. Specifically, the standard requires that the waters reflect the natural seasonal thermal pattern (OAR 340-041-0028(4)(d)). While this standard is different than the natural condition standard (IDAPA 58.01.02.200.09, OAR 340-041-0028(8)), the SR-HC TMDL stated it is difficult to determine what natural temperature conditions are for such a highly regulated system or precisely how altered current conditions are from natural conditions (IDEQ and ODEQ 2004).

The SR-HC TMDL presented a site potential analysis in an attempt to more accurately assess the influence of the HCC on water temperatures downstream. Site potential was defined as the temperature that is predicted to have occurred with direct sources of heat (predominately natural atmospheric inputs) to the mainstem Snake River and without the influence of the HCC, but assuming the current altered hydrologic regime, climate, and tributary inputs (IDEQ and ODEQ 2004). Thus, the SR-HC TMDL used inflow temperatures measured at Brownlee Reservoir as an estimate of site potential in the Snake River downstream of the HCC. This was done despite the fact that the SR-HC TMDL determined that elevated temperatures in the Snake River are primarily due to natural sources and anthropogenic sources, such as upstream and tributary impoundments, water withdrawals, channel straightening and diking, and removal of streamside vegetation that cannot be precisely quantified, and which were not adequately considered in the SR-HC TMDL analysis of site potential. IDEQ and ODEQ acknowledged at the time that this estimate should not be interpreted as natural conditions.

IPC concurred that natural condition temperatures for the Snake River prior to Euro-American settlement cannot be precisely determined. However, during the SR-HC TMDL public comment period, IPC asserted that the SR-HC TMDL temperature analysis improperly ignored upstream anthropogenic effects on water temperature (IPC 2002). In its revised § 401 certification application, IPC presented an alternate analysis to estimate site potential of the Snake River. IPC developed estimated historic (EHist) temperature to illustrate that, while quantifying all upstream anthropogenic effects on temperature may not be possible, estimating additional anthropogenic effects beyond what were captured in the SR-HC TMDL is possible. The EHist temperature analysis does not capture all upstream anthropogenic effects, and therefore, likely attributes more responsibility to the HCC than would exist if the “true” natural conditions were realized.

3.1.1 Estimated Historic Temperature Assumptions

Large-scale anthropogenic development in the Snake River watershed began in the late 1800s. Placer mining was the first to appear (Chandler 2001). As mining activities increased, so did industries that could serve the growing population. Quickly, the watershed was developed for timber harvest and agricultural and livestock production. Some of the most profound hydrologic changes began with the development of irrigation systems. Irrigation systems in the upper Snake River valley served more than 500,000 acres of croplands by 1900 (USBOR 2006). More detail on the anthropogenic development of the Snake River watershed is available in Chandler and Chapman 2001, and Chandler et al. 2001. IPC’s EHist temperature analysis was developed to account for hydrologic and temperature changes in the Snake River due to anthropogenic development. Specifically, the EHist temperature model accounted for water diversion and storage upstream of the HCC; an estimate of unaltered water temperatures in a large river system affected by similar landscape and climatological influences; and natural springs in the Middle Snake River, collectively known as Thousand Springs.

IPC assumed a U.S. Army Corps of Engineers (COE) estimate of unregulated flow upstream of the HCC represented natural hydrologic conditions prior to large-scale anthropogenic development in the Snake River watershed. The COE estimate accounted for storage and diversions (USCOE 2005). Essentially, the current computed local gauge flow below storage facilities was adjusted based on operations or changes in storage. This was termed the adjusted local gauge flow. From the adjusted local gauge flow, diversion flows obtained from the Idaho Department of Water Resources were added. This iterative computation was carried throughout the Snake River watershed and resulted in an estimate of unregulated flow for the Snake River at Weiser, Idaho. The COE unregulated flow estimate was calculated based on daily average flow and thus incorporated seasonal variability in flow.

To use the COE estimate of unregulated flow in the EHist temperature analysis, assumptions of temperature conditions before widespread anthropogenic development were needed because measured water temperature data do not exist. Therefore, a surrogate was used. IPC identified the Salmon River as appropriate for use in the EHist temperature analysis. The Salmon River watershed is situated immediately north of the Snake River inflow to the HCC. Unlike the Snake River, flow from the Salmon River is effectively unregulated. The SR-HC TMDL stated the total storage capacity in the watershed is less than 0.1% of the Salmon River average annual runoff (IDEQ and ODEQ 2004). Large portions of the watershed are in wilderness or roadless areas, and the watershed is very sparsely populated. These factors combine to make the Salmon River, while not pristine, the most natural river in the region of comparable size to the Snake River. In addition, the Salmon River has similar landscape and climatological influences. IPC assumed Salmon River temperatures measured near the confluence with the Snake River (960 ft msl) were representative of temperatures expected in the Snake River inflow to Brownlee Reservoir (2077 ft msl) without spring discharges prior to large-scale anthropogenic development. IPC believes this is a conservative assumption as the Salmon River confluence with the Snake River is located at a lower elevation than Brownlee Reservoir. IPC used daily average temperature data.[2] These data incorporated variability as a result of climatological influences.

The temperature effects of spring discharges on Snake River temperature are included in the EHist temperature analysis. Snake River spring discharge areas occur primarily along two reaches: in the upper Snake River near American Falls Reservoir (RM 675) and in the middle Snake River in an area known as Thousand Springs (RM 585). The Thousand Springs section of the Snake River is a dispersed area covering about 35 river miles. Cumulative discharge has changed over the years with extensive water development in the Snake River watershed. Estimated Thousand Springs cumulative discharge was 4,800 cfs in 1915 increasing to 6,800 cfs in 1955 (IWRRI 2006). IPC assumed the 1915 estimated cumulative discharge of 4,800 cfs best represented the spring discharge prior to large-scale anthropogenic development in the watershed. This estimate is applied as a constant average daily flow and does not account for seasonal variability in spring discharge. The SR-HC TMDL reported the median temperature of ground water inflows to the Snake River were 14.5 ºC (IDEQ and ODEQ 2004). This is corroborated by a mean water temperature of 14.7 ºC reported by Brink and Wilkison (2001) for a predominately spring fed reach of the Malad River, an area in close proximity to Thousand Springs. IPC assumed the Thousand Springs discharge was represented at 14.5 ºC. Climatological influences affect water temperature as water is transported through a watershed. That is, water temperatures tend to reach equilibrium with the climate (e.g., solar radiation, atmospheric air temperatures, wind, humidity). This should not be a factor in applying Salmon River temperatures to the Snake River unregulated flow portion of the inflow to Brownlee Reservoir, however, it may affect spring discharge temperatures applied to the EHist temperature model. IPC did not assume longitudinal warming or cooling of Thousand Springs discharges. Temperature effects from spring water discharged near American Falls Reservoir (RM 675) were not specifically accounted for in the EHist temperature analysis and indirectly were accounted for in the unregulated flow. IWRRI (2006) estimated 2600 cfs is currently discharged to the Snake River in the reach from American Falls Reservoir to Blackfoot, Idaho.

3.1.2 Estimated Historic Temperature Methodology

Data for the EHist temperature model are presented in Exhibit 6.1-1 of the IPC 401 certification application (IPC 2007). Six years were modeled: 1992, 1994, 1995, 1997, 1999, and 2002. These years represented a range in hydrologic conditions (Table 1).

[2] Temperature data were collected using a Hobo® thermistor following standard operating procedures.

Table 1. Snake River average annual flow in cubic feet per second measured at Weiser, Idaho (U.S. Geological Survey gauge 13269000) from 1911 to 2005 and water year categories estimated on pentile (Table 6.1-4 in IPC 2007).

Water Year Category	Average Annual Flow	Model Year (Average Annual Flow)
Low	< 12,800	1992 (8,400), 1994 (10,800), 2002 (11,000)
Medium-low	12,800—15,400	–
Medium	15,400—18,500	1995 (17,500)
Medium-high	18,500—22,900	1999 (22,900)
High	>22,900	1997 (31,300)

Data for any particular year may not be complete. When data were incomplete, IPC substituted data from a similar water year or a lower water year. IPC believes this is a conservative assumption as conditions, flow and temperature, would be more critical in a lower water year. For example, if Salmon River daily average temperature was unavailable for 1994, Salmon River daily average temperature from another low-water year, like 1992, was used to develop a complete data record. The logic sequence used to develop complete data records for the EHist temperature analysis is described in Table 2. The COE began estimating unregulated flow on October 1, 1992. Therefore, 1992 COE unregulated Snake River flow prior to that date is represented by daily average COE unregulated flow from 1994.

Table 2. Salmon River daily average temperature data record development for estimated historic Snake River temperature analysis by model year. Primary choice indicates the year first chosen if data were missing. Secondary choice indicates the next year chosen to complete the data record. NN indicates data substitution not needed (Table 6.1-8 in IPC 2007).

Model Year	Primary Choice	Secondary Choice
1992	NN	
1994	1992	
1995	2000	
1997	1998	1999
1999	1998	
2002	NN	

The EHist temperature model accounts for water diversion and storage upstream of the HCC; an estimate of unaltered water temperatures in a large river system affected by similar landscape and climatological influences; and natural springs in the middle Snake River, collectively known as Thousand Springs. The model (Equation 1) is simply a flow-weighting of Salmon River and Thousand Springs temperatures. Daily average

EHist temperatures for the six modeled years are presented in Exhibit 6.1-2 of the IPC 401 certification application (IPC 2007).

(Equation 1)

$$\frac{(Spring_{Q} \times Spring_{Temp}) + ((Snake\ River\ Unreg_{Q} - Spring_{Q}) \times Salmon\ River_{Temp})}{Snake\ River\ Unreg_{Q}}$$

Where:

$Spring_{Q}$	= historic cumulative flow from Thousand Springs
$Spring_{Temp}$	= median temperature of Thousand Spring discharge
Snake River $Unreg_{Q}$	= Snake River unregulated flow upstream of the HCC
Salmon $River_{Temp}$	= measured Salmon River water temperature

3.1.3 Estimated Historic Temperature Analysis

Current measured inflow temperatures to the HCC were generally warmer than EHist temperatures, nearly yearlong (Figure 1). This was most obvious starting in the spring and persisting through the summer. This period corresponded with the time of year water is being actively managed in the watershed for agricultural uses. This finding is consistent with the conclusion in USEPA (1974) that reported flow depletion due to storage and diversion, and the return of irrigation waters warmed on fields, has resulted in increased warming of Snake River water temperatures.

IPC used EHist temperatures to evaluate current conditions outflow from the HCC relative to the narrative standard that requires the Snake River reflect the natural seasonal thermal pattern. This evaluation indicated that current conditions below the HCC approximate spring and summer EHist temperatures in the low- and medium-water years (Figure 2). This was in contrast to current spring and summer inflow temperatures, which were consistently much warmer than EHist temperatures (Figure 1). In high-water years, like 1997, outflow temperatures from the HCC did not approximate spring EHist temperatures (Figure 2). COE mandated drawdowns of Brownlee Reservoir for flood control, and the resulting shorter residence time in these years, caused spring inflow waters to be more quickly moved through the HCC resulting in outflow temperatures that were very similar to inflow. In addition, current outflow temperatures from the HCC during the falling thermal regime were warmer than the EHist temperatures in all years. This may partly be the result of the HCC absorbing the elevated spring and summer temperatures and distributing the unnatural thermal load through to the fall and early winter. The conclusion was that in the spring and summer of low- and medium-water years the HCC tended to return the Snake River thermal pattern closer to conditions representative of EHist temperatures than the current inflow temperatures. Thus, the effect of the HCC was to moderate the noncompliant inflow thermal regime closer to the natural seasonal thermal pattern most of the year.

The EHist temperature model illustrates that the current HCC inflowing temperatures are unnaturally high because of upstream watershed activities and do not adequately represent site potential as used in the SR-HC TMDL (Figure 1). These elevated temperatures affect the ability of the HCC outflow waters to meet numeric criteria. IPC used CE-QUAL-W2 models and EHist temperature inflow to Brownlee Reservoir to evaluate the effect of the HCC on outflow temperatures. Only the baseline thermal regime was modified. Current flow and operations were not changed. When EHist temperatures were assigned to water flowing into the HCC, outflow temperatures moved toward compliance with the numeric criteria (Figures 3 and 4).

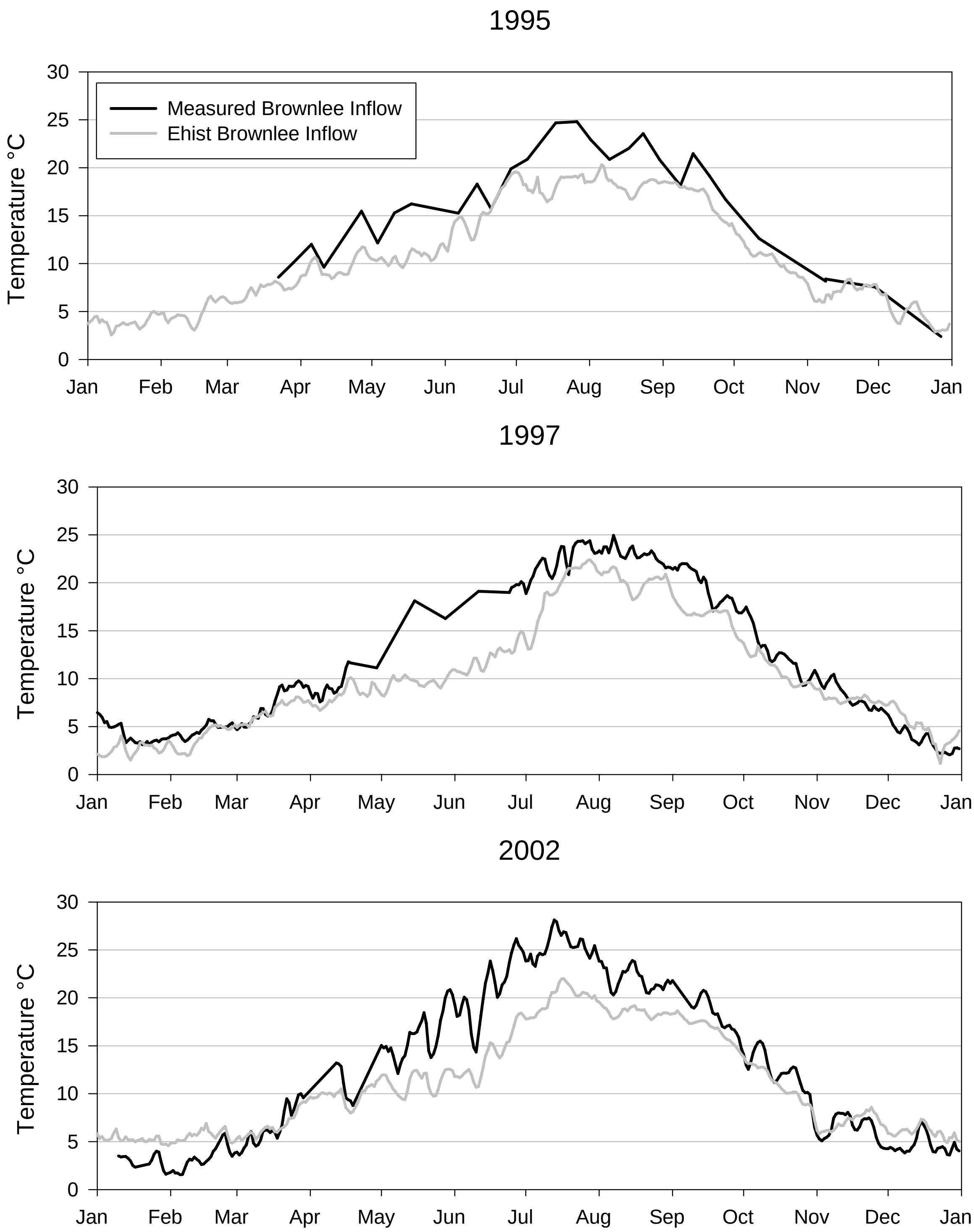

Figure 1. Measured and estimated historic (EHist) temperatures in degree Centigrade (°C) in the Snake River inflow to Brownlee Reservoir for medium (1995), high (1997) and low (2002) water years (Figure 6.1-3 in IPC 2007).

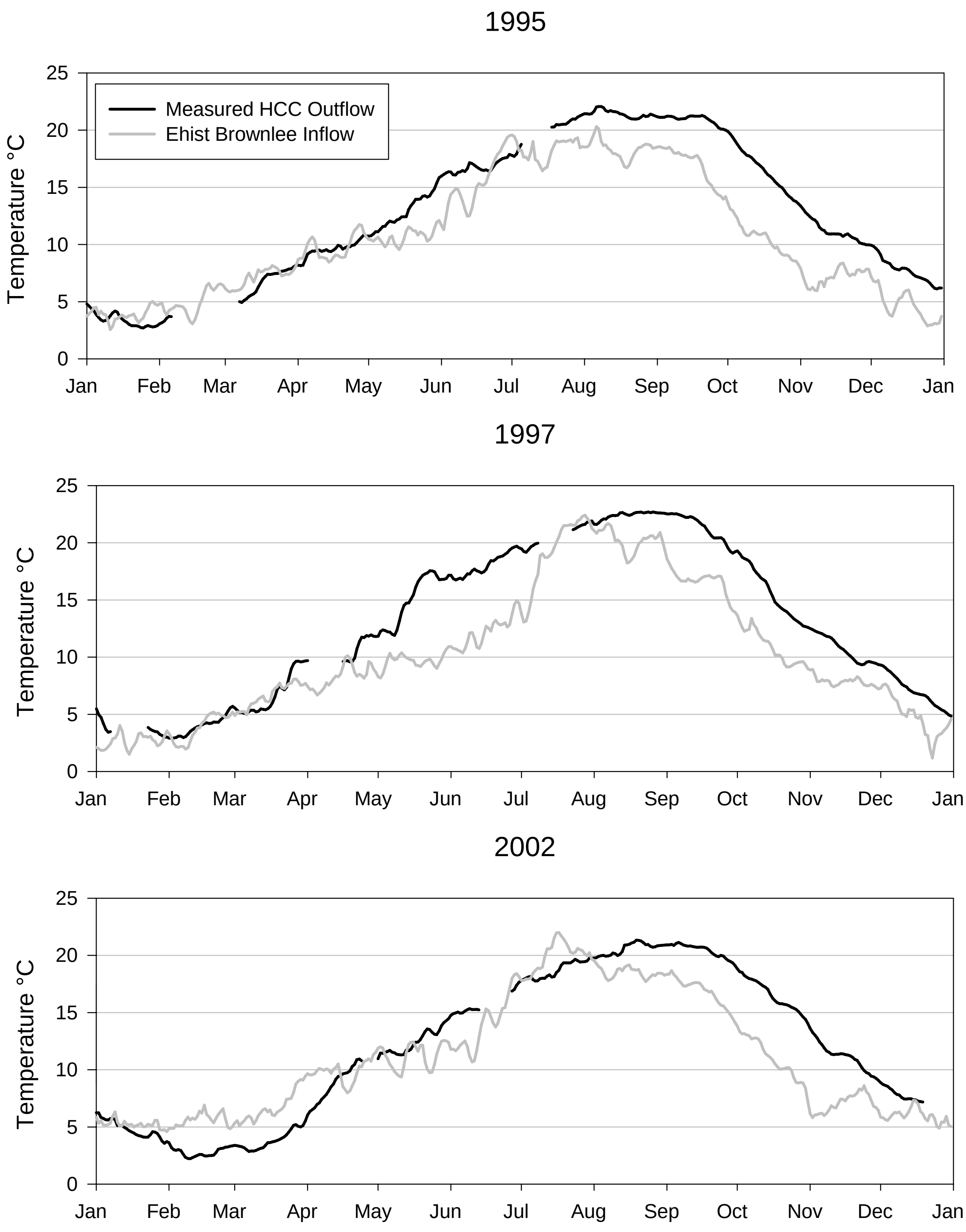

Figure 2. Measured Hells Canyon Complex (HCC) outflow temperatures in degree Centigrade (°C) and estimated historic (EHist) inflow temperatures in the Snake River for medium (1995), high (1997) and low (2002) water years (Figure 6.1-4 from IPC 2007).

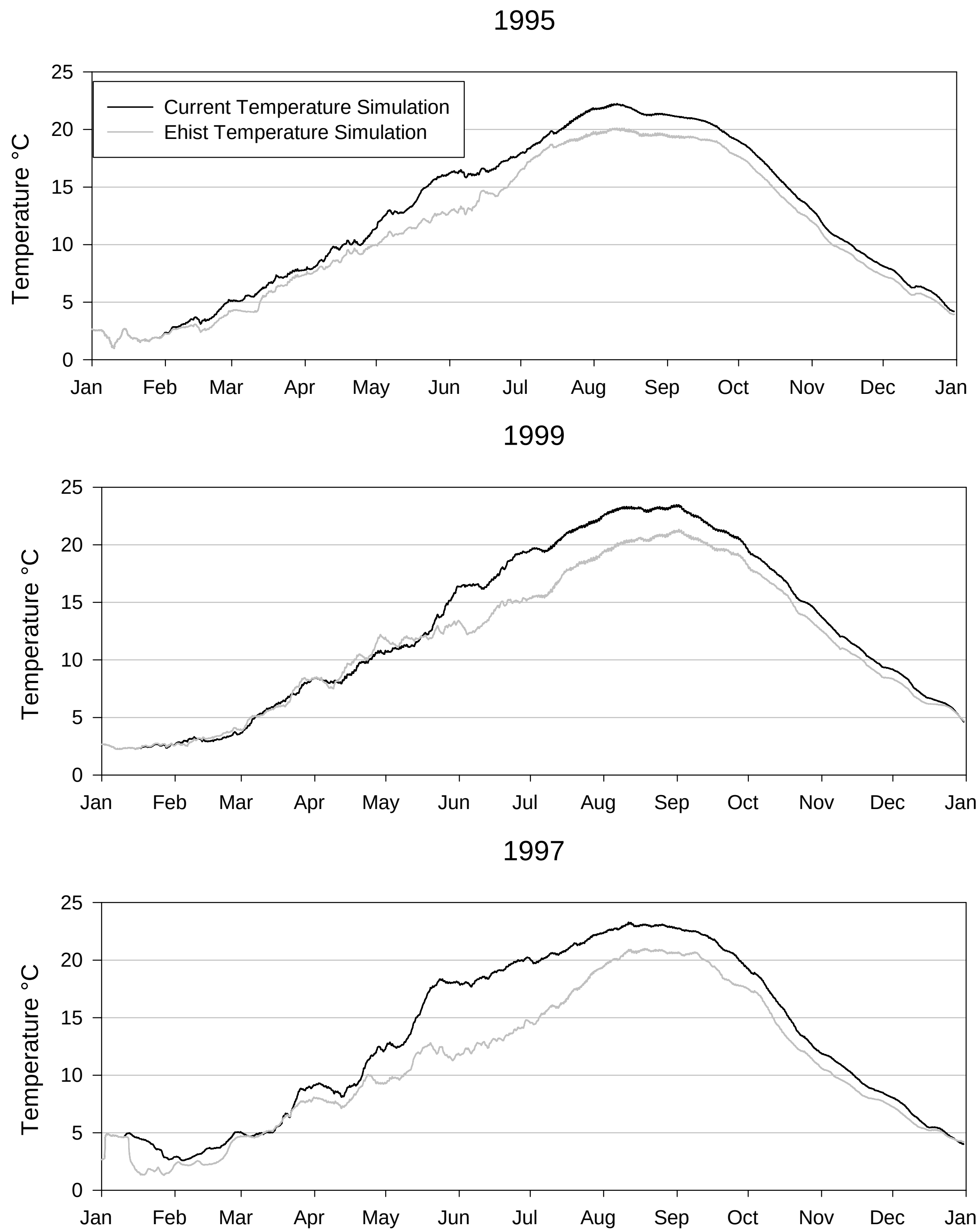

Figure 3. Modeled Hells Canyon Complex outflow temperatures in degree Centigrade (°C) using current (baseline) and estimated historic (EHist) temperatures inflow to Brownlee Reservoir for medium (1995), medium–high (1999) and high (1997) water years (Figure 6.1-5 from IPC 2007).

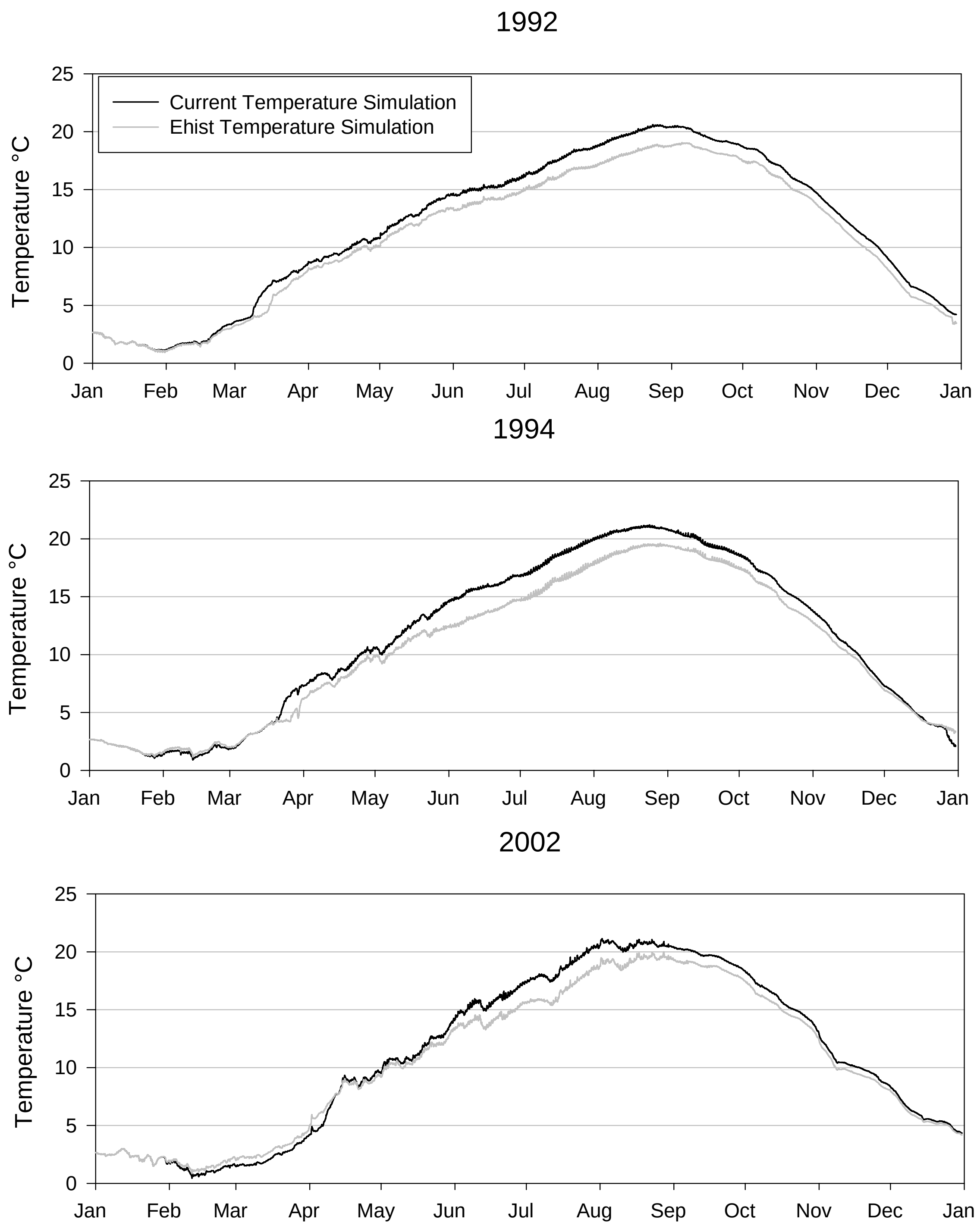

Figure 4. Modeled Hells Canyon Complex outflow temperatures in degree Centigrade (°C) using current (baseline) and estimated historic (EHist) temperatures inflow to Brownlee Reservoir for low water years (1992, 1994 and 2002)(Figure 6.1-6 from IPC 2007).

As discussed above, and demonstrated by EHist, the pre-historic thermal regime below the Hells Canyon Complex substantially differed from the present-day thermal regime and was likely strongly influenced by the inflow of several large tributaries in the area between Swan Falls Dam and the upper portion of what is now Brownlee Reservoir. In this reach of river, the Boise, Payette, Owyhee, Weiser, Malheur and Burnt rivers all enter into the Snake River. This would strongly influence the spring moderated regime upstream of Swan Falls Dam. In addition, the orientation of the high canyon walls in this reach likely limited the solar input during winter months, which contributed to Hells Canyon being a relatively cold over-winter environment, even colder than suggested by EHist, which would represent the Snake River at the point of inflow into Brownlee Reservoir. This colder thermal regime likely affected the production potential of a fall Chinook salmon life history where juveniles initiate seaward migration as an Age-0 fish.

As discussed later (section 4.5), there is little evidence that spawn timing has changed appreciably today as compared to spawn timing prior to the construction of the Hells Canyon Complex below Swan Falls Dam. Spawning was initiated in early October and extended over a relatively prolonged period through early December, with peak spawning occurring around the first week of November (Zimmer 1950). This is very similar to what has been observed today in the spawning area below Hells Canyon Dam. This initiation of spawn timing does not seem strongly tied to a specific water temperatures with the exception that spawning generally takes place when temperature begin to drop below 16ºC and that temperatures are on a declining limb associated with fall cooling (Healey 1991). In fact, spawning has been observed to initiate in water temperatures warmer than 16 ºC. If it is accepted that spawn timing has not appreciably changed, then the influence of different thermal regimes and their effect on emergence timing and outmigration timing of juvenile fall Chinook salmon becomes apparent. IPC hypothesizes that spawn timing of fall Chinook salmon is primarily driven by a declining thermal regime and photoperiod and therefore similar among different rivers and river reaches, and that the effect of different thermal regimes during incubation is manifested in emergence and outmigration timing.

Chandler et al. (2001) compared thermal regimes of different locations in the Snake River relative to emergence timing, including below Bliss Dam (upstream of CJ Strike Reservoir), below Swan Falls Dam (Marsing Reach), downstream of the Weiser River (inflow to Brownlee), Upper Hells Canyon (upstream of Salmon River confluence), Lower Hells Canyon and pre-Hells Canyon Dam (1955-1956; measured at Oxbow, Oregon). For comparative purposes, the Salmon River was also included in the evaluation. In the Bliss Reach, emergence would have been the earliest. Temperatures were relatively stable during the incubation period, and generally did not drop below 7ºC. The latest emergence dates occurred in the Salmon River, with median estimated emergence occurring June 4. Connor (2001) reported estimated emergence timing for the lower Clearwater River as June 17. The Oxbow Reach during the pre-HCC era was also late, with a median emergence date of May 23. Over-winter water temperatures in the Salmon River drop to relatively very low levels. Mean monthly values for December and

January were below 2ºC. The pre-HCC Oxbow reach also reached very low levels and had mean monthly values in January and February below 2ºC. The Salmon River has never been known to support significant numbers of fall Chinook salmon, presumably because of the colder thermal regime. Redds are occasionally observed in the lower Salmon River, but generally represent a very small percentage of the total number of redds observed above Lower Granite Dam (Groves 2001; Groves and Chandler 2001). The similarities between the thermal regime of the Salmon River and the pre-dam Oxbow Reach raise questions as to whether the pre-dam Hells Canyon Reach was capable of meeting its production potential because of thermal limitations.

This comparison demonstrates that emergence timing was correlated with river mile and the altered thermal regime below Hells Canyon Dam shifted emergence present-day earlier than what occurred during the pre-HCC era in the same reach and more in line with the thermal regime upstream of the HCC (Figure 5). The warmer over-winter temperatures likely allow the present-day Hells Canyon Reach to have a higher production potential based on its available present day habitat than what was possible during the pre-HCC era. Similarly, present-day emergence below the Salmon River is also warmer than the pre-HCC era, likely allowing that section of river to reach its production potential based on available habitat. In that regard, the construction of the HCC created thermal conditions that made the 160 km of free-flowing river below Hells Canyon Dam more suitable for fall Chinook salmon spawning than what was evident in the pre-HCC era.

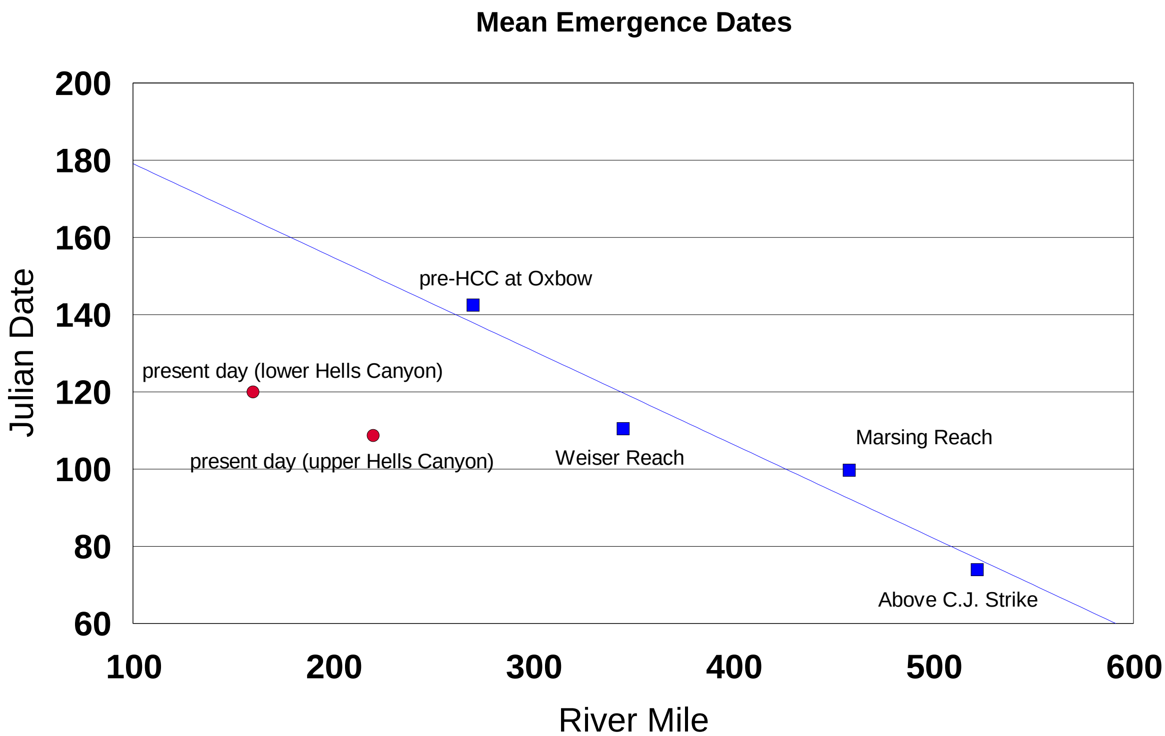

Figure 5. Estimated mean emergence dates of juvenile fall chinook salmon representing the correlation between river mile and emergence day during the pre-Hells Canyon Complex era (blue squares and trend line) and the post Hells Canyon Complex era (red circles).

The effect of Thousand Springs discharge, inflowing near RM 585, on the Snake River thermal regime is evident today with winter temperatures as high as 9 ºC in the reach below Bliss Dam (RM 540). Before the construction of Swan Falls Dam, the middle Snake River in this area was the major producer of Snake River fall Chinook salmon. This comparison demonstrates the influence spring flows had on fall Chinook salmon that allowed them to historically occupy the middle Snake River. Discharges from springs to the Snake River provided critical historic water temperatures that aided fall Chinook salmon embryo development. Spring waters warmed the Snake River during the winter, providing for an earlier fall Chinook salmon emergence than would be expected under a non-spring influenced system and this benefit diminished downstream. This is likely the major reason fall Chinook salmon did not become established in the Salmon River system. Earlier emergence because of warmer winter temperatures was likely an ecological benefit because of the increased distance these fish had to travel to migrate to the ocean. Earlier emergence allowed the ocean-type life history of migrating to the ocean after only a brief rearing period following emergence (the dominant life history) to escape warmer summer temperatures. Early emergence allowed sufficient growth to initiate early migration.

4. Significance of Present-day Thermal Regime to Fall Chinook Salmon

There has been much discussion regarding the potential effects of a thermal shift in the fall prolonging exposure of Snake River fall Chinook salmon to warmer fall temperatures. In this section, we analyzed the different life stages of fall Chinook salmon relative to the thermal shift. Upon review of the information, it is the conclusion of IPC that this thermal shift has had an overall positive effect on Snake River fall Chinook salmon below Hells Canyon Dam because it has allowed fall Chinook salmon to be productive in a reach that prior to construction may not have been able to support significant production. This is significant because historic fall Chinook salmon spawning habitats are either too degraded today to support fall Chinook salmon or are inundated thus leaving the Hells Canyon Reach the only mainstem Snake River habitat suitable to support fall Chinook salmon.

4.1 Adult Migration

Several authors have concluded that elevated water temperatures may adversely affect adult salmon migration. Observations have been reported of adult Chinook salmon upriver migration being stalled or stopped at water temperatures generally greater than 19.0°C (Fish and Hanavan 1948, Sams and Conover 1969, Hallock et al. 1970, Stabler 1981, Alabaster 1988, Bumgarner et al. 1997, Peery et al. 2003). Only three of those references are specific to fall Chinook salmon (Sams and Conover 1969, Hallock et al. 1970, Peery et al. 2003), and only two are specific to or reference Snake River fall Chinook salmon (Sams and Conover 1969, and Peery et al. 2003).

A discussion of adult fall Chinook salmon upstream migration within the Snake River, relative to water temperature, is found within two EPA reports (McCullough 1999, McCullough et al. 2001). Both reports note that historic passage of those fish occurred from late August through November, with a peak in September. Passage data at Ice Harbor Dam (the lowermost dam on the Snake River) shows that from 1964 through 2006 passage of adult fall Chinook salmon has continued to begin in mid-August, peak by about mid-September, and be complete by late-November. The same is presently true for fish passing Lower Granite Dam.

Both EPA reports infer that, due to elevated water temperatures (between 21-25°C) in Lower Granite Reservoir during the period from 13 August to 16 September 1990, a migration blockage of about four weeks occurred, and likely occurs every year. The authors acknowledge that 1990 was one of the warmest years on record, and this event occurred prior to when Dworshak Reservoir discharges began to be used to cool the lower Snake River. If a four week migration blockage had occurred during 1990, then Chinook salmon passage in 1990 should have been near zero during that time period. However, passage data for 1990 shows that 95 adult and 25 jack Chinook salmon passed

Lower Granite during the time period of the warmest water temperature. These fish represented 24% and 13% of each group's total, respectively, of adult and jack fall Chinook salmon counted past Lower Granite Dam during 1990. On average, 33% of adult and 13% of jack fall Chinook salmon tend to pass Lower Granite by 16 September (based on fish passage data from 1974 through 2006). The 24% adult and 13% jack passage during the elevated water temperature period of 1990 does not support the contention that a "migration block" occurred, or occurs in the Snake River.

Sams and Conover (1969) hypothesized that either elevated temperature by itself, or a strong difference in temperature between migration areas might result in either a delay or blockage of migration of Chinook salmon. These authors concluded that water temperatures as high as 22.8°C did not constitute a migration blockage for fall Chinook salmon, nor did their results support that a difference in temperature as large as 5.0°C between two migration areas would cause a delay or blockage to upstream adult migration. They did note that decreased oxygen levels (less than about 4 mg/L) when coupled with elevated water temperature were more likely to cause a migration delay or blockage, than was elevated temperature by itself. Hallock et al. (1970) reported similar conclusions for fall Chinook salmon of the Sacramento-San Joaquin River basin.

In a more recent study, Peery et al. (2003) noted that historic water temperatures at the mouth of the Snake River (prior to any of the lower Snake River dams and the upper river Hells Canyon Complex) were consistently over 20.0°C through mid-September. These authors also reported that water temperatures at the mouth of the Snake River were above 20.0°C for an average of about 71 days historically, but only about 39 days presently. Additionally, since the 1940's mean monthly water temperatures have tended to decrease at the mouth of the Snake River during June, July, and August, remain similar during September, and have slightly increased during October (Peery et al. 2003). However, while those authors report a slight increase for the month of October, it is clear from their data that this is only due to a low sample size, and the inclusion of one very cold year for that monthly period (refer to Figure 6 in their report).

Unfortunately, Peery et al. (2003) were not able to continue their historic/contemporary comparisons to locations further upstream in the Snake River. Limited water temperature data do exist for an area near the present-day location of the Lower Granite Dam (Central Ferry; 1955-1958). Historically, water temperature at Central Ferry tended to increase above 20.0°C by about early July and increase above 21.0°C by about mid-July. Water temperatures tended to reach a maximum of about 25.0°C by about mid-August, remain above 21.0°C until about early September, and finally decrease below 20.0°C by about mid-September. As well, water temperatures at Central Ferry remained above 20.0°C for an average of 71 days; this is similar to what was reported for the mouth of the Snake River by Peery et al. (2003). In comparison, Peery et al. (2003) reported that overall, for the years 1995 through 1998, water temperatures at Lower Granite Dam first reached 20.0°C by about mid July, generally peaked in late July, and tended to finally drop back below 20.0°C by late-September. The average period that water temperatures presently tend to remain above 20.0°C at Lower Granite Dam is 60 days, and the peak temperature averages about 22.0°C (3.0°C cooler than historic temperature maximum).

Based on the above information, it appears that adult fall Chinook salmon presently enter and migrate through the lower Snake River during a time-frame consistent with what is believed to have occurred historically (pre-1964). However, and this is significantly more important, those fish presently appear to experience a similar period of exposure to temperatures elevated above 20.0°C (mid-August through mid-September), but experience a much lower maximum temperature. This is also a conclusion of Peery et al. (2003). This information indicates that fall Chinook salmon do not presently experience a more hostile environment during their upstream migration than they did historically.

Peery et al. (2003) concluded that the passage of low numbers of radio-tagged adults during the warmer period of their study indicated that either a block or a migration delay can occur. Peery et al. (2003) also noted that the 25% passage quartile tended to be completed later in years when water temperatures were warmer. However, it is noteworthy that the adult Chinook salmon used in this study were tagged at Bonneville Dam, and that no data are presented as to the actual timing of the tagging of those fish. Without knowing when the fish were tagged, it is questionable whether the observations of a few radio-tagged fish passing Ice Harbor and Lower Granite dams during mid-July through mid-September were due to water temperature causing a passage block or delay, or more simply because few to no fish were tagged during that period. Water temperatures at Bonneville Dam during their study were consistently ≥20.0°C for the periods from about 29 July – 10 September 1997, and 17 July – 8 September 1998. It is normally not considered prudent to tag adult Chinook salmon when water temperatures are ≥20.0°C (Mendel et al. 1992) due to increased potential for stress-related mortality from handling. Also, while few to none of their radio-tagged subjects were observed passing the two dams during the early period of fall Chinook passage (mid-August through mid-September), it should be noted that only two adult fall Chinook salmon were tagged in 1997, and in both years (1997 and 1998) a large number of un-tagged Chinook salmon were counted (36% and 20% of each years' total run, respectively) during that period at each dam as they passed upstream.

Finally, there is the potential for salmonids to behaviorally regulate their internal body temperatures (Berman 1990, Berman and Quinn 1991). These reports show that adult Chinook salmon are adept at locating and holding in thermal refugia, maintaining their internal body temperatures as much as 2.5°C cooler than ambient water column temperatures. While the presence or amount of potential thermal refugia is unknown throughout the Snake River (either downstream or upstream of Lower Granite Dam), data from 1995 through 2006 show that the water temperature in the tailrace of Lower Granite Dam, during the period 18 August through 30 September, averaged 1.3°C cooler than in the forebay (range 0.4 – 2.1°C cooler). As well, the mean water temperature for that period was 18.4°C in the tailrace and 19.7°C in the forebay. It is reasonable to infer that thermal refugia exist throughout the Snake River, whether in deeper pools, at the mouths of tributaries, or in areas of cooler groundwater upwelling.

In conclusion, there has been no apparent shift in adult migration timing. Adult fall Chinook salmon experience a similar period of exposure to temperatures elevated above

20 ºC between mid-August and mid-September as they did pre-HCC, but experience a lower maximum temperature than occurred historically. This is based on water temperatures present at Central Ferry in the early to mid-1950's, prior to construction of the HCC or the lower Snake River reservoirs.

4.2 Pre-spawn mortality

Some level of pre-spawn mortality is common among salmon populations. Concern is often expressed as to whether excessive pre-spawn mortality occurs in fall Chinook salmon of the Snake River and if it can be linked to elevated water temperature exposure. In McCullough (1999) and McCullough et al. (2001), several references are listed that indicate that temperatures ≤15.0°C in hatchery holding ponds result in the highest survival of adult Chinook salmon prior to spawning. All of the pertinent literature available pertaining to Chinook salmon pre-spawn mortality in relation to water temperature is based on studies of spring or summer Chinook salmon (Coutant 1970, Becker 1973, Lindsay et al. 1989, Berman 1990, Jensen et al. 2005, Jensen et al. 2006). The actual cause of death in most all cases is outbreak of disease associated with long exposure times (as much as seven weeks) at elevated water temperatures (≥19.0°C) and fish being held in stressful conditions and in close contact with each other (e.g. hatchery holding ponds).

Elevated water temperature during adult holding is not necessarily lethal, and may not always result in elevated pre-spawn mortality (Burrows 1960). A major objective of Burrows (1960) was to assist hatchery developers in designing and constructing the most efficient types of adult holding ponds. The author noted that, over a 10-year period at the Entiat hatchery in Washington, even though maximum water temperatures were as high as 22.5°C, and adults were held on average for about three months (which included the warmest seasonal period), there were no statistical differences in survival when compared with cooler years. After examining differences at two different hatcheries (Entiat and Leavenworth), the author noted that the most likely cause of the lower survival rates of spring Chinook salmon at the Leavenworth hatchery was due to a poor flow-through of supply water, not elevated water temperature.

In a study by Berman (1990), spring Chinook salmon adults were maintained at constant control (≈14°C) and test (≈19°C) temperatures for 45 days. At the end of that time period the control fish appeared to be in good shape; however, all but two of the test fish (both males) had perished. Following the loss of the test fish, the control lot was split into a new control and two test groups. The new control group was again maintained at ≈14°C, and the two new test groups were again maintained at ≈19°C. After a period of at least 15 days there were no observed mortalities in either test group. While the actual objective of the study was not to determine how long adult spring Chinook salmon could be held at elevated water temperature without mortality occurring, it does indicate that prolonged holding of adult spring Chinook salmon at water temperatures approximately 19°C can result in significant pre-spawn mortality. It would not be unusual that higher temperatures would produce similar results, and likely take a shorter period of exposure to do so.

Additionally, two recent papers (Jensen et al. 2005, Jensen et al. 2006) provide further evidence that increased pre-spawn mortality can occur if adult Chinook salmon are exposed to elevated water temperatures for a lengthy period of time. In Jensen et al. (2005), adult summer Chinook salmon held in two naturally declining thermal regimes, one heated and one chilled (with respect to ambient river conditions), resulted in overall pre-spawn mortality values of 71% and 58%, respectively. However, what is interesting is that both groups were on-station by 18 August, and by 20 October both groups of fish had experienced equal pre-spawn mortality of 58%. Because the fish in the chilled group had all matured and were spawned by 20 October, there were none to maintain past that date. The authors initially believed that the heated thermal group experienced delayed gamete maturation; however, during a second year of study, that was not the case. During the second year of study (Jensen et al. 2006) all test fish in chilled, ambient, and heated temperature test tanks perished by 1 September, prior to maturation and spawning. However, pre-spawn mortality could be estimated for female fish held in ambient river temperature raceways (46%) and constant cold temperature tanks (8%). The difficulty with this data was that an undetermined, high incidence of predation had occurred to the population of fish maintained in the ambient temperature raceways, which makes the prespawn estimate of 46% inconclusive. In addition, the control fish were held at constant cold (≈9°C) temperatures, which makes application to a natural environment such as a large river difficult. However, it is again reasonable to assume from their data that maintaining adult Chinook salmon at water temperatures consistently ≥19.0°C for approximately 40-45 days will result in elevated pre-spawn mortality. These papers generally confirm the findings reported by Berman (1990).

This information has limited application to the Snake River. Adult fall Chinook salmon generally begin to enter the Snake River by about mid-August. The U.S. Army Corps of Engineers designates 12 August and 18 August as the dates from when salmon passing Ice Harbor and Lower Granite dams, respectively, are deemed fall Chinook salmon. Since 1995, the mean number of days (during the adult fall Chinook salmon passage period) that water temperature is ≥19.0°C in the tailrace of Ice Harbor and Lower Granite Dams is 40 (range 23-55) and 5 (range 0-27), respectively. As an added note, about 57% (mean of passage data for 1964-2005) of the adult fall Chinook run passes Ice Harbor Dam during the first 40 days of passage, when water temperatures in the tailrace can be expected to be ≥19.0°C. Based on this information, it would not be surprising if individual fish remaining in the tailrace of Ice Harbor Dam for as many as 40 days might be subject to pre-spawn mortality. However, a migrating fish remaining in a tailrace for that duration is not likely to occur. The median time for radio-tagged Chinook salmon (combination of spring and fall adult data) to pass Ice Harbor Dam was 16.9 hours in 1997 and 14.4 hours in 1998 (Peery et al. 2003). A shorter amount of time was required to pass the dam during periods when water temperature was the warmest. These authors also reported a median travel time between Ice Harbor and Lower Granite dams of 3.9 days in 1997, and 3.6 days in 1998. These data indicate that while fall Chinook salmon do enter the Snake River when water temperature can be considered lethal over an extended time period, the fish do not typically remain in these warmer conditions for the extended period of time that would suggest the occurrence of high pre-spawn mortality.

As discussed in the previous section on adult migrations, thermal refugia likely exist throughout the Snake River (i.e. confluence of the Clearwater and Snake rivers and near the mouths of several smaller tributaries).

Another indicator of pre-spawn mortality can be the fish to redd ratios determined for fall Chinook salmon upstream of Lower Granite Dam. It has been noted that early fish to redd ratios within the Snake River Basin (previous to 1993) indicated that a very large proportion of the adult population were unaccounted for based on the number of observed redds, and this was often presumed to be because of high levels of pre-spawn mortality. Fish to redd ratios during the period 1986-1992 averaged 24.0, with a very wide range of 7.0-110.3. While these early numbers were cause for concern, it should be understood that only a very limited number of redd surveys, covering a limited portion of potential habitat, were conducted during those years. Another factor in those early years was that there was no attempt to compensate for fallback of adult Chinook salmon (or over-counts) at Lower Granite Dam, or deep-water spawning that was not detectable from the aerial surveys in either the mainstem Snake or Clearwater rivers. Since 1993 a very extensive effort has been expended to count fall Chinook salmon redds in habitats upstream of Lower Granite Dam. Aerial surveys are conducted weekly in the mainstem Snake River, as well as the Clearwater, Grande Ronde, and Imnaha rivers (major tributaries). Additional aerial surveys are conducted within the Salmon River and in the lower portions of a few of the smaller tributaries. Finally, a significant effort is undertaken to enumerate deep-water spawning at many sites in the Snake River using remote underwater video; however, this type of survey method continues to be lacking in the Clearwater River. When all of these data are compiled and analyzed relative to the total number of adult fall Chinook salmon allowed to pass upstream of Lower Granite Dam (with fallback and over-counting at the dam taken into account), the resulting fish to redd ratio has averaged 3.2 (range 2.0-4.2, data from 1993-2006). This comports well with (or better than) estimates of fish to redd ratios for the Hanford Reach of the Columbia River (3.0-16.0), where pre-spawn mortality is not considered to be a problem (Visser et al. 2002), and has never been reported as “excessive”.

It is reasonable to assume that if adult fall Chinook salmon remained for long periods of time where water temperatures remain ≥19.0°C, then significant pre-spawn mortality could likely occur. It is also apparent that water temperature near the mouth of the Snake River can be ≥19.0°C for extended periods of time during the fall Chinook salmon adult migration. If adult fall Chinook salmon were to remain in that area for long periods of time, pre-spawn mortality could be a concern. However, adults do not remain in the vicinity of the mouth of the Snake River (near Ice Harbor Dam) for prolonged periods (especially when it is warm), and they appear to migrate rapidly upstream to cooler reaches (near Lower Granite Dam). Berman (1990) had no trouble maintaining adult spring Chinook salmon at temperatures approximately 19°C for at least 15 days. Additionally, fish to redd ratios for the Snake River upstream of Lower Granite Dam provide further evidence that pre-spawn mortality is not a significant problem.

4.3 Gamete Viability

Another concern relative to pre-spawn exposure to warmer temperatures is a potential reduction in gamete viability which ultimately could lead to a reduced fitness (see reviews in McCullough 1999, and McCullough et al. 2001). These two reports offer a review of available literature of which most refer to species other than Chinook salmon. In fact, it appears that sockeye salmon (Andrew and Geen 1960, Bouck et al. 1975, Gilhousen 1980), coho salmon (Flett et al. 1996), pink salmon (Jensen et al. 2004), rainbow trout (Billard 1985), or brook trout (Hokanson et al. 1973) have been the primary species of study in this area. In these reviews, the Jensen et al. (2004) report on pink salmon is extensively referenced by the authors when making conclusions regarding Chinook salmon embryo viability.

Prior to exploring several references that are specific for Chinook salmon on the topic of reduced gamete success, one aspect of this area of research is noteworthy. Studies concerning this topic vary considerably in their results. Many of the studies cited (although not specific to Chinook salmon) demonstrate that egg and sperm quality can be reduced if “ripe” adults are held for extended periods at consistently high water temperatures. However, there is no evidence presented in these reviews that Chinook salmon adults holding in warmer waters but under a declining thermal regime are subject to reduced gamete viability. Therefore, the applicability of these reviews to not only Chinook salmon but also to natural populations of Chinook salmon experiencing a declining thermal regime that occurs in the natural environment is questionable.

Several reports specific to Chinook salmon that are commonly cited on the topic of gamete viability and temperature include: Hinze et al. (1956), Hinze (1959), Rice (1960), Jewett (1970), Jewett and Menchen (1970), CDWR (1988), Berman and Quinn (1989), Berman (1990), Marine (1992), Jensen et al. (2005). Two of these (CDWR 1988, and Marine 1992) are literature reviews similar to those of McCullough (1999) and McCullough et al. (2001). The following sections will explore in detail these studies and will compare their findings relative to conditions that Snake River fall Chinook salmon experience.

4.3.1 Hinze et al. (1956)

The Hinze et al. (1956) paper is specific to a fall Chinook salmon stock of the American River, California. The authors’ main question centered on whether egg incubation at the newly constructed Nimbus Hatchery would be adequate when operational water was provided from a new upstream reservoir. Hinze et al. (1956) reports on the first year of Nimbus Hatchery operations. The upstream reservoir from where their operational water originated had just been filled during the previous months for the first time. There was no formal experiment conducted and reported on in this report; this was an annual hatchery operation report. Aside form potential elevated temperature problems, it was noted that several other water quality problems within the hatchery persisted throughout the incubation period, including: reduced dissolved oxygen through mid-November, elevated sulfides (which at very low levels are toxic to developing embryos), gas super-saturation, and increased turbidity. Early egg-take lots suffered elevated mortality, and this was attributed solely to elevated temperature during adult maturation and the egg-take period. This conclusion was determined only from discussion among various hatchery personnel and not from “scientific” testing. Further, while the authors concluded that elevated water temperature during adult holding was the primary factor for increased embryo mortality, they also stated, “***No facts have been gathered to back up this supposition***”. As such, this report should not be cited as evidence leading to conclusions for decreased gamete viability relative to water temperature. The other water quality problems, other than gas super-saturation, were not considered as potential causes to mortality. The egg-lots that are reported as suffering the highest mortality were spawned at water temperatures ≥16.7°C. There is no data presented in the report pertaining to mortality within individual egg lots.

When comparing the maximum daily water temperature data provided in Hinze et al. (1956) to what is generally observed within the Snake River during the fall Chinook salmon spawning period (Figure 6), it is evident that the conditions of the Nimbus hatchery are not comparable to the Snake River. Adult holding temperatures (estimated for 5 October -25 October in this report) averaged 20.0°C (with a relatively stable range between 20.6-19.4°C) at Nimbus Hatchery, compared to 16.9°C (with a declining range between 18.4-15.4°C) for the same time period in the upper Hells Canyon Reach (the warmest area during the fall period) of the Snake River. As well, water temperature at the Nimbus Hatchery during the fall of 1955 remained ≥16.5°C through 10 November, by which time the peak of spawning had occurred. This is in stark contrast to water temperatures in the upper Hells Canyon Reach of the Snake River that generally drop below 16.5°C by about 20 October. While the water temperatures in both systems drop at similar rates from early October through late December, water temperatures at the Nimbus Hatchery averaged 3.3°C warmer (range 1.4-5.1°C) than the upper Hells Canyon Reach of the Snake River. It is certainly possible that elevated water temperature at the Nimbus Hatchery during adult holding (averaging 20.0°C for at least 20 days just prior to spawning), and remaining elevated above 16.5°C through early incubation and peak spawning (an additional 15 days), could have been factors contributing to increased embryo mortality. However, this is not a situation comparable to that of the Snake River.

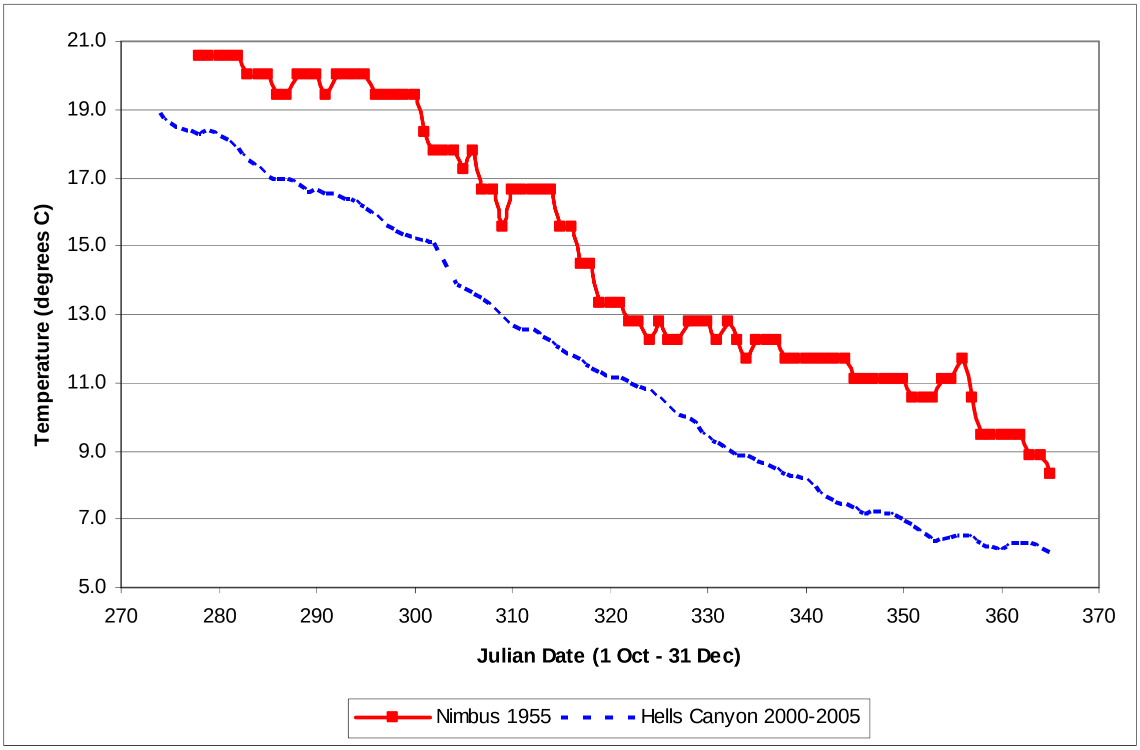

Figure 6. Comparison of maximum daily water temperature reported for Nimbus hatchery (1955) and the mean daily maximum temperature in the upper Hells Canyon Reach of the Snake River (2000-2005).

4.3.2 Hinze (1959)

The Hinze (1959) paper is also specific to fall Chinook salmon of the American River, California. Again, the main question discussed in this paper was whether egg incubation at the Nimbus Hatchery was feasible when operational water was provided from an upstream reservoir. Hinze (1959) reports on the third year of Nimbus Hatchery operations. While this was also an annual hatchery report, there was an attempt to conduct a formal experiment on adult holding temperatures and potential effects to gamete success. Adult Chinook salmon from the American River were able to be maintained at the Nimbus Hatchery for about 10 days prior to mortality when water temperatures were between 15.0-19.4°C, while adults transported to Kyburz (a cold-water holding base) could be kept alive for about 6 weeks at temperatures between 4.4-10.0°C. However, while adult Chinook salmon could be kept alive at the lower temperature, their gametes did not ripen and they had to be returned to Nimbus Hatchery and placed in warmer water (13.6-14.4°C) to allow their gametes to ripen. Eggs finally taken from the Kyburz-held fish were subjected to several spawning and incubation environments. Results are as follows:

1. Eggs spawned and incubated at water temperature ≥16.7°C suffered 100% mortality;
2. Eggs spawned and incubated at water temperatures between 15.6-16.7°C suffered 50% mortality to the eyed stage;
3. Eggs spawned and incubated at water temperatures between 12.8-13.3°C suffered 20% mortality to the eyed stage;
4. Eggs spawned between 15.6-16.7°C and then incubated at temperatures between 12.8-13.3°C suffered 30% mortality to the eyed stage;
5. Eggs that were spawned and incubated at water temperatures between 1.1-3.3°C suffered 100% mortality.

While these results are interesting relative to spawn and incubation temperatures, they are not applicable to the question of gamete viability as a result of pre-spawn exposure to elevated water temperatures.

In an effort to establish a new strain of Chinook salmon at the Nimbus Hatchery, 51 adults (15 male and 36 female) were transported to the Nimbus Hatchery from the Klamath River. These fish were on-station at Nimbus Hatchery by 29 September, when the daily maximum water temperature was 18.1°C and rising. By 22 October, only 7 (5 males and 2 females) of the original 51 Klamath River test adults remained alive. The mean daily maximum water temperatures during that 24-day holding period had been 18.9°C (range of 18.1-19.4°C). Only one of the Klamath River females was able to be spawned, on 22 October, at a temperature of 18.3°C. As a comparison, a single American River female was spawned on the same date, at the same temperature. Both groups of eggs attained the eyed stage on 11 November. The mean daily maximum water temperature from 22 October through 11 November was 17.8°C (range of 16.4-19.2°C). Only 16% of the American River eggs and 35% of the Klamath River eggs survived to the eyed stage. Through the rest of the incubation period, only 1.3% of the American River and 16% of the Klamath River eggs survived to the hatch stage. No fry were maintained past 26 February, when only 6 individual Klamath River fry remained alive. Conclusions relative to prespawn temperature conditions and gamete viability cannot be reached from this evaluation because of the confounding factors of high temperature during the incubation period to the eyed stage. Both stocks performed poorly from a sample size of one female from each group.

Comparing the water temperature data provided in the Hinze (1959) report to what is generally observed within the Snake River when fall Chinook salmon spawn (Figure 7), shows that adult holding temperatures (estimated as 1-22 October for this report) averaged 18.9°C (with a fairly stable range of 19.6-18.1°C) at Nimbus Hatchery, compared to 17.4°C (with a declining range between 18.9-16.1°C) for the same time period in the upper Hells Canyon Reach of the Snake River. As well, water temperature at the Nimbus Hatchery during the fall of 1957 remained ≥16.5°C through 11 November. This is in stark contrast to water temperatures in the upper Hells Canyon Reach of the Snake River which generally drop below 16.5°C by about 20 October. During the 1957 fall season, the water temperature at the Nimbus Hatchery declined at a rate of 0.1°C per day, in contrast to the rate of decline normally observed in the Snake River of about 0.2°C per day. As well, water temperatures at the Nimbus Hatchery averaged 3.8°C warmer (range 0.3-6.2°C) than the upper Hells Canyon Reach of the Snake River throughout the period 1 October through 31 December. It is possible that elevated water temperature at the Nimbus Hatchery during adult holding (averaging 18.9°C for at least 22 days just prior to spawning), and remaining elevated above 16.5°C through early incubation and peak spawning, was a factor contributing to increased embryo mortality. However, this report is not a good citation to support the effects of elevated water temperature on gamete viability because of the confounding factors of high temperature during the incubation period to the eyed stage nor, because of the significant differences in temperature data is it useable to compare with conditions relative to the Snake River and fall Chinook salmon.

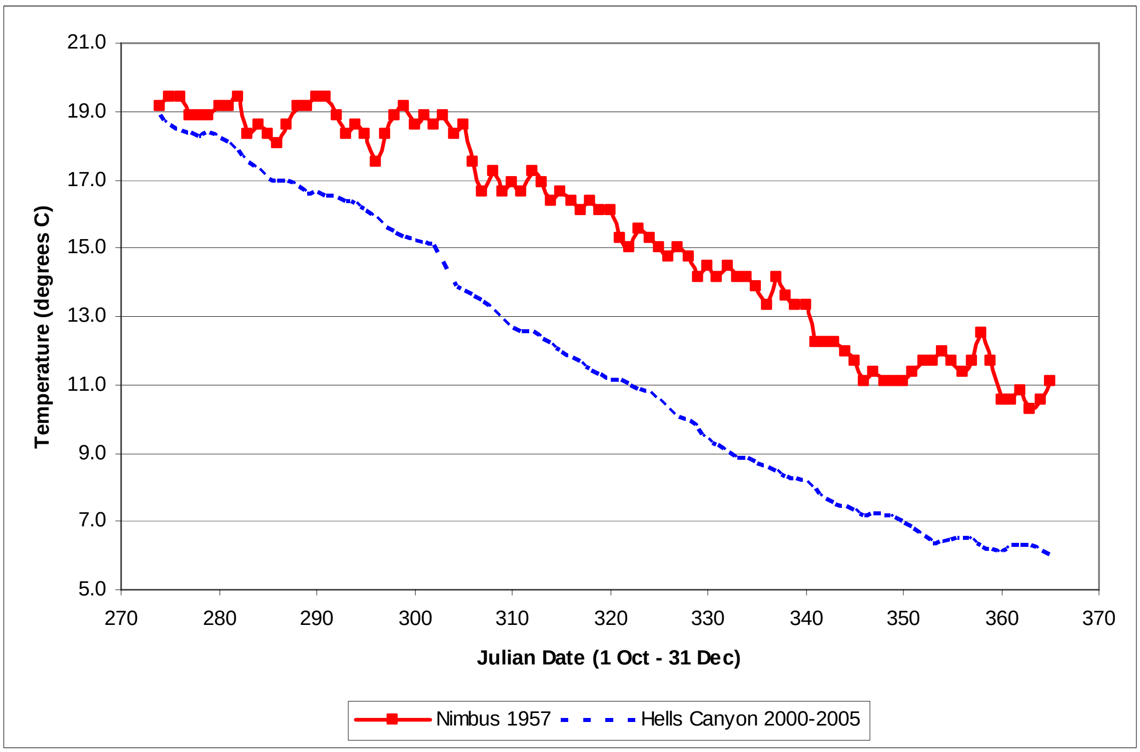

Figure 7. Comparison of maximum daily water temperature reported for Nimbus hatchery (1957) and the mean daily maximum temperature in the upper Hells Canyon Reach of the Snake River (2000-2005).

4.3.3 Rice (1960)

The Rice (1960) report is also specific to fall Chinook salmon of the American River, California. The main question discussed in this paper was whether delayed embryo mortality at the Nimbus Hatchery was a direct result of elevated water temperature (≥15.6°C). An attempt was made to conduct an experiment; however, it is difficult to determine the actual conditions during the pre-spawn, spawn, and incubation phases being tested in the experiment.

In this experiment, adult Chinook salmon were trapped in the American River and hauled to the Bear River cold-water holding station. There were three groups of eggs from which data were collected, and embryos were only maintained through the eyed stage. One group was spawned at Bear River and were incubated through the eyed stage at Bear River, a second group was spawned at Bear River and were then transferred to, and incubated to the eyed stage at, Nimbus Hatchery, and the third group was spawned at Nimbus Hatchery and then taken to and incubated through the eyed stage at the Bear River station. The results were that the eggs spawned and incubated at Bear River (adults held and spawned and eggs incubated in cold water) had a 53.9% survival to the eyed stage, the eggs spawned at Bear River and incubated at Nimbus Hatchery (adults held and spawned in cold water and eggs incubated in warm water) had a 35.4% survival to the eyed stage, and the eggs spawned at Nimbus and then incubated at Bear River (adults held and spawned in warm and eggs incubated in cold water) had a 41.3% survival to the eyed stage.

Unfortunately, there is no description of the actual thermal regime that pre-spawn adults were exposed to, at what temperature eggs were spawned at, or the thermal regime that each egg group was subjected to. Also, because the eggs were apparently maintained as one large group in each treatment, there is no way to statistically analyze the results. Finally, other circumstances (other than water temperature) are referred to that caused embryo mortality, including: smothering, fungus growth, and exposure to direct sunlight. In the end, the results from this report are inconclusive relative to the question of pre-spawn exposure to elevated water temperatures and gamete viability.

4.3.4 Jewett and Menchen (1970)

The Jewett and Menchen (1970) report is specific to a fall Chinook stock from the Mokelumne River, California. This report describes the artificial spawning channel (and its maintenance and operation) on the Mokelumne River, as well as an incubation survival test conducted in the hatchery building. Adult Chinook salmon were allowed to enter and remain in an artificial spawning channel having a gravel bottom and water running through it that was diverted from the Mokelumne River. The water temperature in the channel was equal to what was observed in the Mokelumne River. Adult salmon were allowed to spawn naturally in the channel, their carcasses were collected afterward, and an estimate was made as to the number of eggs deposited in the gravel. After juveniles emerged, they were captured in a downstream trap and enumerated as they emigrated from the channel; the managers estimated production from the resulting juvenile numbers and estimate of deposited eggs. This report also details a specific test that was performed in order to learn more about how elevated water temperature during early spawning may have affected the survival of later developing embryos.

During the test (in the fall of 1966), 12 female Chinook salmon were spawned, and their eggs were maintained in the hatchery building. The eggs were split into three groups and were maintained in different thermal regimes. Resulting fry were maintained through feeding and the survivors were planted into the Mokelumne River in May of 1967. There are no dates provided for the spawn-timing of the females, and the actual thermal regime experienced by pre-spawn adults and each egg group is not provided. The only details provided are as follows:

1. Eggs from three females were spawned at temperatures between 13.9-15.6°C; eggs from one of the females were too green and they all perished; eggs from the other two females resulted in final fry survival of 72.2%.
2. Eggs from three females were spawned at 14.4°C; the final fry survival was 74.5%.
3. Eggs from six females were spawned at temperatures between 12.2-12.8°C; eggs from one of the females were too green and they all perished; eggs from the remaining females resulted in final fry survival of 84.6%.

Because of the way the samples were produced and maintained, it is not possible to statistically analyze the results from this test, and the differences observed may not represent statistical differences. The authors concluded that water temperature during early spawning resulted in elevated mortality of developing embryos. It is more likely that elevated water temperature throughout the greater part of early embryo development (the first three weeks of November) was a more reasonable explanation for the observed mortality. Figure 8 demonstrates that for a brief period, water temperatures during the early incubation exceeded 17°C in this study. Geist et al. (2006) demonstrated that for periods less than the exposure in this study to water temperatures of 17°C caused significant mortality. Regardless, this study should not be cited as an evaluation of gamete viability relative to pre-spawn temperature exposure.

A comparison of the maximum daily water temperature data provided for the Mokelumne River in the Jewett and Menchen (1970) report to what is generally observed within the upper Hells Canyon Reach of the Snake River when fall Chinook salmon spawn (Figure 8) again shows very different thermal regimes between these rivers. The daily maximum mean water temperature within the Snake River (16.7°C) is typically warmer than what was reported for the Mokelumne River in 1966 (16.2°C) during the adult holding period (roughly 1-31 October). However, while the Snake River thermal regime typically declines from about 18.9°C to 14.0°C during this period, the Mokelumne River temperature tended to ***increase*** from 15.6°C to 17.2°C. Also, water temperature in the Snake River tends to average 11.3°C during November (with a declining regime from about 14.0°C to 9.0°C), while the Mokelumne River averaged 15.1°C (with a slightly declining regime from about 16.0°C to 14.5°C). It is reasonable to conclude that within the Mokelumne River elevated incubation temperatures throughout the entire month of November would have had a significantly negative effect on embryo survival.

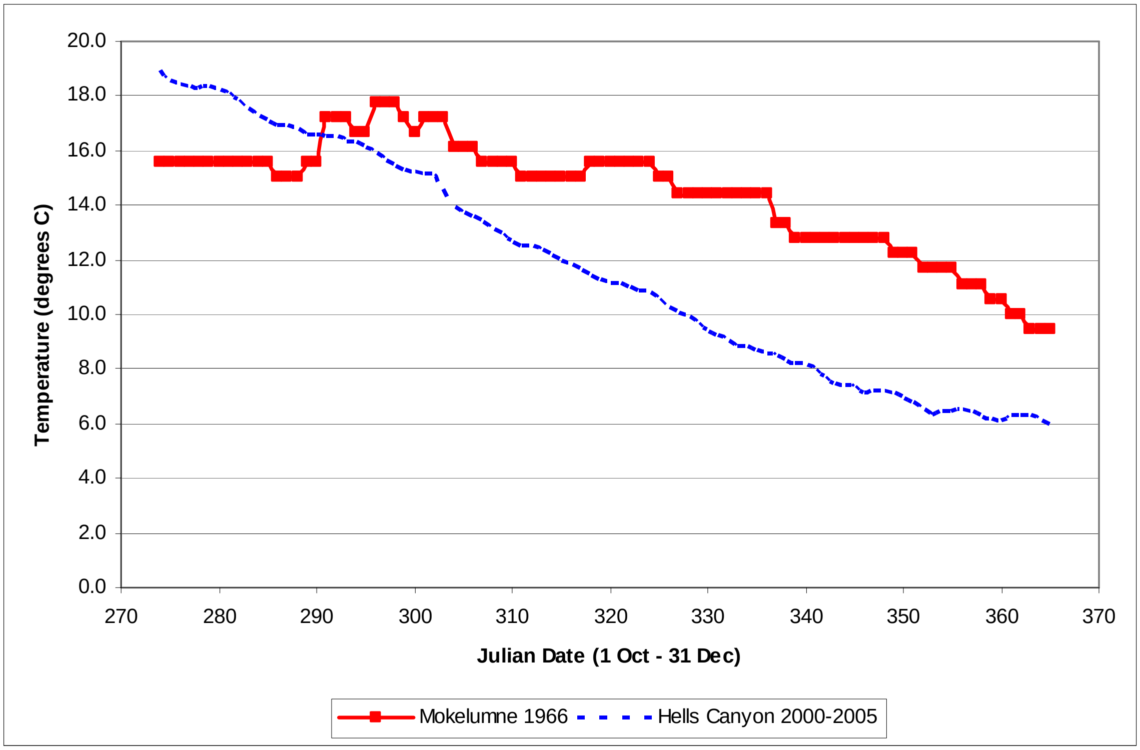

Figure 8. Comparison of maximum daily water temperature reported for the Mokelumne River (1966) and the mean daily maximum temperature in the upper Hells Canyon Reach of the Snake River (2000-2005).

4.3.5 Jewett (1970)

The Jewett (1970) report is also specific to fall Chinook salmon of the Mokelumne River, California. Low estimated production in previous years was thought to have resulted from elevated water temperature (approximately 15.6-16.1°C) during pre-spawn holding. The managers hypothesized that the warm holding temperatures were harming the developing eggs within the females. Therefore, during the fall of 1967, an incubation test was performed. Unfortunately, there is little detail as to the experimental design of the study. Four females were spawned with four males, and the fertilized eggs were maintained in a hatchery building. However, there is no information as to the dates when the gametes were fertilized or of the actual water temperatures at the time of spawning. It is noted that at the time of spawning, eggs from the females were in various stage of development, from too green to over-ripe. It is also mentioned that the water temperature did not drop below 15.6°C until 16 days after the eggs were fertilized. Based on the limited information provided in the narrative, and the daily record of water temperature provided in the appendix of the report, it appears that spawning took place during the second week of November, when water temperatures were between 16.1-16.7°C. From the total number of test eggs that were able to be fertilized, 67% survived to the hatch stage, and 28% of the total survived to the planting stage.

The main conclusion derived from the experiment was that elevated water temperature during adult holding (pre-spawn) was the reason for depressed survival of embryos through the planting stage. However, the data presented do not support this conclusion. The author did not consider the possibility that maintaining the fertilized embryos at fairly constant, elevated temperatures for a lengthy period (≥15.6°C for 16 days) may have been a cause for elevated embryo mortality.

As with the Nimbus Hatchery evaluation (Hinze et al. 1956, Hinze 1959, Rice 1960), it is interesting to compare the plots of the maximum daily water temperature data provided in the Jewett (1970) report to what is generally observed within the Snake River when fall Chinook salmon spawn (Figure 9). The mean daily maximum temperature during the estimated adult holding period (1-31 October) for the Mokelumne River was lower (15.2°C) than what is generally observed in the upper Hells Canyon Reach of the Snake River (16.7°C). However, the thermal regime in the Mokelumne River ***increased*** during that period, from a low of 13.9°C to a high of 16.1°C, as compared to the Snake River, which typically declines from 18.9°C to 14.0°C. The most noticeable difference in the thermal regimes of the two rivers is that the Mokelumne River remained relatively stable and ≥15.0°C throughout the period 8 October through 29 November, while the Snake River is characterized by a continuously declining regime that is typically at 18.1°C on 8 October, drops below 15.0°C by 30 October, and by 29 November is just below 9.0°C.

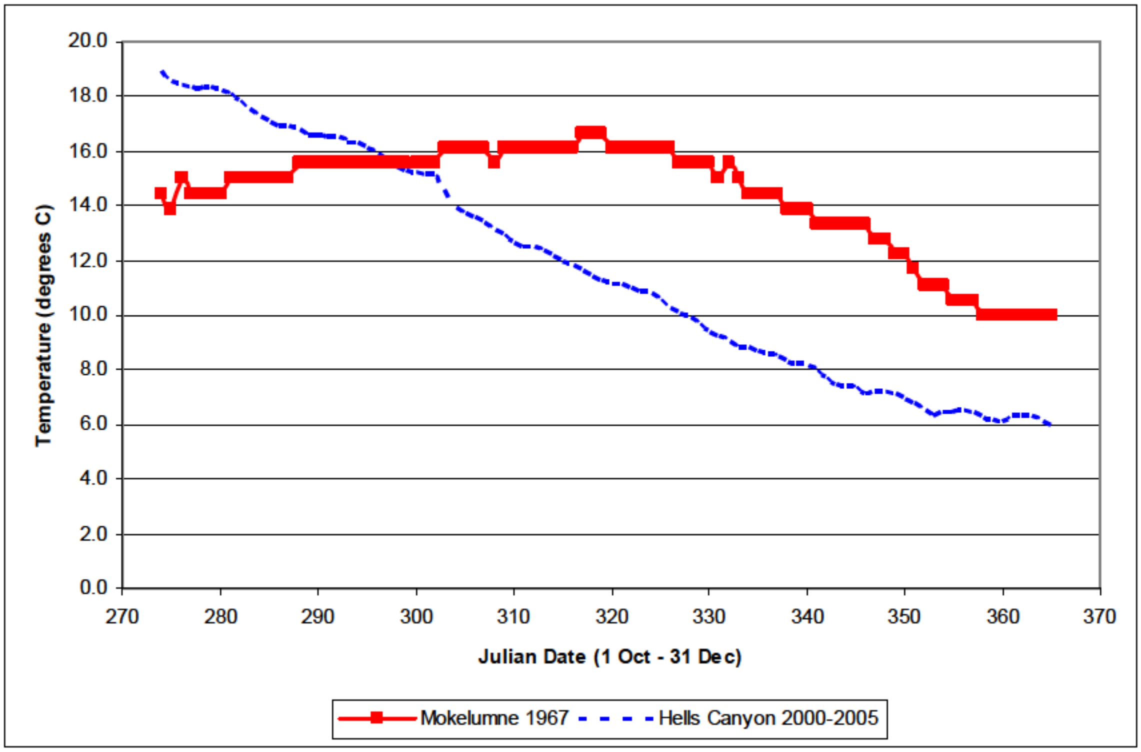

Figure 9. Comparison of maximum daily water temperature reported for the Mokelumne River (1967) and the mean daily maximum temperature in the upper Hells Canyon Reach of the Snake River (2000-2005).

4..3.6 Berman and Quinn (1989)

This report is an annual progress report of a University of Washington Masters' thesis. This report discusses a pilot project that was conducted in order to test the feasibility of holding adult Chinook salmon at two different, fairly constant, water temperatures over an extended period prior to spawning. It was hoped in the original design that adults could be held at the two temperatures and spawned afterward; the embryos would then be maintained through development in order to determine if elevated water temperature during holding affected reproductive success. The fish used in this test were spring Chinook salmon from the Kalama Falls State Hatchery. The results from this pilot project are often cited in support of reproductive success being reduced due to elevated adult holding temperature (e.g. McCullough et al. 2001), contrary to the following admonition of the authors: **"Interpretation of results from the pilot study were complicated by the presence of several confounding variables. Thus, when reviewing data derived from the pilot study it is imperative that differences between the treatment groups not be attributed solely to temperature."** The authors also conclude: **"… it is difficult to determine from the records whether mortalities were related to temperature or other variables such as disease outbreak or sediment load that may affect egg survival."**

Initial test fish entered the hatchery by 3 August and were maintained on-station until 30 August. Twenty females were selected and tagged, split into two groups of ten, and then transferred into two different holding environments. Ten females were maintained in a cold environment at a local spring and experienced fairly constant water temperatures between 4.4-6.0°C. The other ten females were kept at the hatchery and were placed in a pond with the rest of the hatchery fish; these fish would have experienced water temperatures between 10.0-16.7°C. All fish used for the pilot study were spawned during the first week of September. The following observations are noteworthy:

1. At the time of spawning, all of the originally tagged females in the hatchery (warm-water group) had shed their tags, and new females with unknown thermal histories had to be chosen.
2. A fungal infection ran rampant through the cold-water control group of females, and only four remained alive at the time of spawning.
3. After spawning a portion of the eggs was maintained at the University of Washington at constant 9.0°C and a portion was maintained at the hatchery at an undisclosed temperature.
4. Eggs kept at the university were maintained through the hatch stage, while eggs at the hatchery were kept through the eyed stage.
5. Average mortality through the eyed stage was 8% for eggs from the warm-water females, and 36% for the eggs from the cold-water females.
6. Both treatment groups showed similar mortality rates through hatching.

In sum, this report provides no evidence that elevated pre-spawn holding temperatures, as high as 16.7°C, result in reduced viability of Chinook salmon gametes.

4.3.7 Berman (1990)

This document is a completed Masters' thesis from the University of Washington, and is tied directly to Berman and Quinn (1989). The main study species is spring Chinook salmon of the Yakima River. The actual thesis has three separate main objectives:

1. Determine if elevated pre-spawn holding temperatures negatively affect Chinook salmon gamete viability.
2. Determine if pre-spawn Chinook salmon in the wild can behaviorally regulate their internal body temperature to alleviate exposure to elevated water temperature.
3. Model Yakima River water temperatures in order to determine the extent of degradation potentially caused by stream-bank logging, and whether mitigation actions might be able to restore the historic thermal regime.

The results from the first main objective are often cited to support the proposition that elevated water temperature during pre-spawn adult holding has a significant, negative effect on Chinook salmon gamete viability. For the first objective, 33 adults were trapped at Roza Dam and transferred to Priest Rapids Hatchery on the Columbia River. The holding test began on 26 June. These fish were split into two almost equal groups. Until 7 July, all fish were maintained at about 14.0°C. Afterward, one group (control) was kept at about 14.0°C (range 14.0-15.5°C), and the second group (test) was kept at about 19.0°C (range 17.5-19.0°C). The experimental design was to keep all fish alive and spawn them; however, by 20 August (45 day period) all but two of the test fish had perished. The two remaining fish were males. Therefore, the control group was then split to produce one new control and two new test groups. The new control group continued to be maintained at about 14.0°C, and both of the new test groups were maintained at about 19.0°C. Both test groups were maintained at about 19.0°C through 4 September (15 day period). Spawning of all fish took place from 18 September through 3 October. Unfertilized gametes were collected at Priest Rapids, transferred to the University of Washington, and were then mixed. Five hundred eggs from each female were kept; this resulted in a total of 1000 eggs from the control group, 1500 eggs from test group one, and 1000 eggs from test group two. All eggs were maintained at a constant 9.5°C throughout incubation. Because of the way the eggs were grouped, it was impossible to statistically analyze the results. **All embryos (control and test) perished within 24 hours post-hatch.** This unfortunate event makes it difficult to scientifically accept the value of any of the results stemming from this part of the study. Prior to 100% mortality, there had been 1 pre-hatch mortality in the control group (0.1% mortality), 12 pre-hatch mortalities in test group one (0.8% mortality), and 9 pre-hatch mortalities in test group two (0.9% mortality). The size and weight of the test alevins appeared to be less than the control alevins, but this could not be statistically validated.

The results from the first objective of this thesis are scientifically unsound, and do not support the hypothesis that elevated temperature during adult holding results in decreased gamete viability. However, results do suggest that if spring Chinook salmon adults remain at constant temperatures of about 19.0°C for 45 days, they will perish, but that 15 days at that temperature will not result in elevated pre-spawn mortality.

4.3.8 Jensen et al. (2005)

This study used summer Chinook salmon from the Puntledge River on Vancouver Island, British Columbia, Canada. It was undertaken because there was concern that elevated water temperature experienced by the natural population in the Puntledge River might be causing increased mortality, especially with respect to gamete viability due to adult pre-spawn temperature exposure.

All adults used for this study were captured during the summer of 2003 and held on-station until spawning that fall. Adults were maintained in six circular holding tanks under similar densities, and were provided with similar water circulation and dissolved oxygen saturation conditions. Two tanks were maintained at ambient temperatures for the Puntledge River, two were exposed to temperature conditions that were elevated over the ambient regime, by about +2.0°C, and two were maintained at temperature conditions that were chilled by about -2.0° below the ambient regime.

The authors noted that an anomalous event occurred around mid-September (when water sources were altered), resulting in 100% mortality of females and 58% loss of males in the ambient temperature group of adults. They stated that this event was sudden and had nothing to do with the ambient water temperature.

The only comparison that could be attempted at that point was between the chilled and heated group of fish. Both females and males within the heated group experienced elevated pre-spawn mortality when compared with the chilled group. Female pre-spawn mortality was 83% for the heated group compared to 36% for the chilled group. Male pre-spawn mortality was 33% for the heated group compared to 8% for the chilled group. These were statistically significant differences. The authors noted that maturation tended to occur later for the heated group (mean of 8 November) as compared to the chilled group (mean of 18 October). This was not a statistically significant difference.

Eggs from females of both groups were taken and immediately maintained under what the authors considered good to excellent thermal conditions for incubation. A statistical test of difference between mortality in the chilled and heated groups was not attempted; however, it is possible to accomplish this because of the way the eggs were maintained. The authors noted that the quality of gametes from all test subjects, both chilled and heated, appeared to be in very good condition, and that this was very different from what was observed with pink salmon during a previous study (Jensen et al. 2004). Embryos for each group were maintained through the ponding stage (past emergence). Final embryo mortality for the chilled group was 5.1% compared to 1.5% for the heated group. There was no statistically significant difference in final embryo mortality.

Additionally, the authors collected data on egg size prior to spawning. They did not attempt to statistically test whether a difference existed between the chilled and heated groups; however, they did note that there did not appear to be a difference.

The authors concluded several times that the results with Chinook salmon were very different from what they observed for pink salmon (Jensen et al. 2004). Egg quality was observed to be degraded in pink salmon, especially in the heated groups, while this was not the case for Chinook salmon. Final embryo mortalities in the pink salmon tests were higher for both chilled (13.5%) and heated (60.2%) groups as compared to Chinook salmon.

4.3.9 Jensen et al. (2006)

This study was an attempt to reproduce the 2003 work (Jensen et al. 2005). The study species again was the Puntledge River summer Chinook salmon.

The entire experimental design was modified relative to the 2003 evaluation, and it is difficult to compare results from the two studies. Several different groups were maintained during this study: one group was split and held in the chilled, ambient, and heated temperature tanks as in the previous work, one group was collected and held in a raceway at the upper Puntledge River Hatchery site, one group was collected and held at a raceway at the lower Puntledge Hatchery site, and a final group was collected at Puntledge, and transported and held in a large tank at the Rosewall Hatchery. The fish held in both the upper and lower Puntledge Hatchery raceway sites were exposed to ambient Puntledge River water temperatures. The fish held at Rosewall were supplied with fairly constant temperature (7.8 – 9.0°C) spring water.

The objective of the experiment was to test for differences in pre-spawn mortality in the chilled, ambient, and heated tanks at Puntledge Hatchery, to test for differences in spermatocrit values across all exposure groups, and to test for embryo mortality across all pre-spawn temperature exposure groups. Embryos were incubated at a constant temperature of 12.0°C, and were only maintained through the hatch stage.

A change in operations at the upstream hydroproject affected water quality in the Puntledge Hatchery holding tanks, and this led to early, complete mortality of all female adults in the chilled, ambient, and heated temperature tanks by 1 September. A graphic of mortality by date indicates that total mortality occurred in the chilled group first. However, the researchers noted that the change in upstream dam operations mobilized large amounts of sediment and silica-algae in the main river, which was entrained through the experimental tanks. They believed that complications due to the increased sediment load resulted in severe irritation to gill membranes, which led to the massive loss of fish in all Puntledge Hatchery experimental tanks.

Fish in the upper and lower Puntledge River Hatchery raceways and in the Rosewall Hatchery pond were ultimately spawned, and comparisons were made between those three groups. It is very important to understand that fish in the Puntledge Hatchery raceways were not able to seek out thermal refugia (as fish in a natural environment might be able to do) and they were continuously exposed to elevated water temperatures (>19.0°C) for approximately 40 days. In contrast, the Rosewall fish were exposed to water temperatures that fluctuated between only 7.8-9.0°C, a condition not normally present in a natural river system.

Pre-spawn mortality of females in the upper and lower Puntledge Hatchery raceways could not be definitively calculated because the initial number of fish in the raceways was unknown, and there was a reported high loss of adults to predation. However, relative mortality calculated for females on hand at the time of spawning was 46% for both Puntledge sites combined, while the Rosewall group experienced 8% mortality.

The maturation rate of gametes was noted as being similar across both Puntledge Hatchery and Rosewall groups of fish. This was different than what was observed for Chinook salmon during the 2003 trials.

Spermatocrit values averaged 40% (Rosewall), 36% (lower Puntledge), and 28% (upper Puntledge). Rosewall and lower Puntledge values were statistically similar, while the upper Puntledge value was determined to be statistically lower than the other two. However, the authors concluded that this was not biologically significant, as eggs from

Rosewall were fertilized with milt from males held at both Rosewall and the upper Puntledge site, and no difference was detected in the survival of those embryos.

Embryo mortality through the hatch stage was similar between the two Punteldge Hatchery groups (11.8% and 13.4%), but was statistically higher than what was observed for the Rosewall group (3.1%). Again, it was noted that these values were different than what was observed for pink salmon during an earlier experiment (Jensen et al. 2004).

The average egg weight was lowest for the females held at the Rosewall site; however, there was no statistical significance across the three groups.

These final two studies conducted by Jensen et al. (2005) and Jensen et al. (2006) appear to be the best information presently available concerning how elevated water temperature during holding can result in increased pre-spawn mortality, as well as how gamete viability may be affected if adults are maintained for long periods of time at elevated temperatures. It is important to understand that these studies (like Berman 1990) held adults at elevated water temperature (>19.0°C) for an extended period of time, approximately 40 days, prior to spawning. Also, while one of the studies indicates that no differences in gamete viability occurred between a chilled and heated thermal group of fish, the second one did show that gamete viability was statistically different between groups of females exposed to different thermal environments. However, the test that showed differences held females at constant, low temperatures (which would not occur in a natural river environment), and compared the viability of their gametes with fish held in a naturally occurring thermal environment of a river. While this test did result in differences in gamete viability, it is uncertain if the 12-13% embryo mortality would represent an expected range for natural spawning adults in a more normative river environment as compared to the low constant temperatures to which the data were compared. Finally, the authors noted several times throughout these two papers that results for Chinook salmon and pink salmon (Jensen et al. 2004) were very different, and it would be unwise to view the two species as functional equivalents.

After review of these commonly cited studies relative to gamete viability, it appears that only the Jensen et al. (2006) evaluation supported the hypothesis that gamete viability can be affected by pre-spawn water temperature conditions. However, it remains unclear whether elevated water temperature during the pre-spawn adult holding period under a declining natural thermal regime would result in negative effects to embryonic development in Chinook salmon. Certainly, prolonged exposure (40 days in these experiments) of adult spring Chinook salmon to elevated water temperatures does appear to result in elevated pre-spawn mortality and in the case of Jensen et al. (2006) may affect gamete viability. Snake River fall Chinook currently do not face the extreme conditions used in the Jensen et al. (2006) study. Clearly, more research is needed in this area to determine the differences relative to the length of exposure to elevated water temperature and gamete viability under a thermal pattern that represents the declining thermal regime of a fall spawning fish.

4.4 Disease Susceptibility

It is common knowledge that disease effects can become exacerbated in Chinook salmon adults when they are exposed for prolonged periods of elevated water temperatures in the pre-spawn environment, especially when they are held in close, confined, stressful quarters (such as hatchery ponds and raceways). However, as discussed above under pre-spawn mortality, the thermal environment of the lower Snake River today is cooler during the early portion of the adult migration period (through about the end of September). The temperature presently drops below the 20°C criteria established for protecting adult migrating anadromous salmonids at a time that is comparable to historic conditions. After the river cools below 20°C the rate of cooling is not as rapid today as it was prior to the construction of the Hells Canyon Complex, but the water temperature remains below the protective criteria. There is no evidence of major disease outbreaks occurring in the natural population of returning adult fall Chinook salmon that presently migrate upstream past the four lower Snake River dams. This is supported by the low fish to redd ratios observed in the Snake River Basin (discussed earlier), which do not indicate that problems due to disease or pre-spawn mortality in general in the natural population upstream of Lower Granite Dam is of concern.

4.5 Spawn Timing

Elevated water temperatures can affect physiological and physical processes such as the rate of gamete maturation within adults or potentially suppressing an environmental cue such as that associated with the process of redd construction and spawning. For the Snake River below Hells Canyon and other rivers such as the Grande Ronde and Clearwater, there are several years of empirical data on spawning activity of Snake River fall Chinook salmon and corresponding water temperature information. There are also some data available on historic spawn timing prior to the construction of the Hells Canyon Complex. These data can be used to help further examine if spawn time has changed and potentially help examine the feasibility of altering spawn-timing by manipulating water temperature.

Several researchers have attempted to maintain adult Chinook salmon at elevated water temperatures prior to spawning. Berman (1990) maintained adult spring Chinook salmon at constant test and control temperatures of approximately 19°C and approximately 14°C (respectively) for approximately two weeks prior to spawning. From her descriptions, there appeared to be no delay in gamete maturation in the fish maintained at the elevated test temperature. Jensen et al. (2005) maintained adult summer Chinook salmon at two different test temperatures that followed a normal, local river thermal regime. The two test thermal regimes were kept approximately 2.0°C warmer and colder than the ambient river temperature. The warm group was subjected to temperatures ≥19.0°C for 42 days (with a maximum mean temperature of 22.8°C). The cool group experienced a maximum temperature of only 18.3°C). This is a substantial difference in thermal environments.

The authors noted that the warm group had later gamete maturation timing than did the cooler group, approximately a three week difference. However, only two females remained alive in the heated group, and it is possible that these could have just been late maturing fish, and water temperature had nothing to do with the gamete maturation differences observed. As well, the authors reported that the gametes from the two fish of the warm thermal test group had gametes of good quality, which was obviously different than what had been observed for pink salmon in an earlier experiment (Jensen et al. 2004). Jensen et al. (2006) again maintained summer Chinook salmon at two different thermal regimes prior to spawning. Their control group was maintained at a fairly constant temperature of approximately 9°C. Their test group of Chinook salmon was maintained at ambient river temperatures; these test fish experienced temperatures ≥19.0°C for about 40 days (with a maximum mean temperature of 22.0°C). The ambient test group of this experiment experienced a similar thermal regime as the fish from the heated test from the previous experiment. Results were very different from what was observed during the previous experiment; no difference was observed in the rate of gamete maturation between the control and test groups. Maturation of gametes occurs over a protracted time period, as represented by the protracted range of natural spawning observed. For example, Zimmer (1950) reported fall Chinook salmon to spawn from late September to early December in the Snake River upstream and prior to construction of the Hells Canyon Complex.

Within the Snake River, adult fall Chinook salmon can pass into and hold within several different river reaches, all having different thermal characteristics. As well, if adult fish within the Snake River are experiencing less than optimal water temperature, they have the ability to freely move among the various reaches and seek out thermal refuges. Fish held for experimental or cultural purposes of course do not have the ability or freedom to seek out thermal refuges unless this was specifically provided in the experimental design. If migrating adult fall Chinook salmon were to remain in the vicinity of Ice Harbor Dam (close to the mouth of the Snake River), it is conceivable that they could be exposed to temperatures ≥19.0°C for about 46 days (with a maximum mean temperature of about 22.0°C). However, as has been discussed earlier, migrating adult salmon have been observed to quickly move through these areas (Peery et al. 2003). Similarly, if adult fall Chinook salmon remained in the vicinity of Lower Granite Dam, it is conceivable that they could be exposed to temperatures of approximately 19°C for about 28 days (with a maximum mean temperature of about 18.5°C). It generally takes adult salmon only a couple of days to navigate through the Lower Granite Reservoir and into the vicinity of the lower Clearwater River and the lower Hells Canyon Reach of the Snake River. It may only take a few days longer to move upstream into the upper Hells Canyon Reach of the Snake River. Fish moving into the Clearwater River (where spawning has been observed to start earlier than in the Snake River) would immediately experience significantly cooler temperatures (generally a maximum of approximately 15°C). Near the confluence of the Snake and Clearwater rivers, there is a significant cool water refuge available for upstream migrating adult fall Chinook salmon, largely because of the cooling effect of releasing water from Dworshak Reservoir. The ***earliest*** fish entering the lower Hells Canyon Reach of the Snake River could conceivably experience water temperatures ≥19.0°C for about 32 days (with a maximum mean temperature of about 22.0°C). Again, if these fish experience thermal stress, they could move back downstream into a more amenable thermal refuge near or in the Clearwater River, or could even continue moving upstream into areas where other thermal refuges exist. For example, water entering the Snake River from the Grande Ronde River (Snake RM 168) tends to be <19.0°C by 1 September, and is cooling rapidly. There are also similar cool water refuges further upriver near the mouths of the Salmon and Imnaha rivers, and at many other smaller tributaries throughout the upper Hells Canyon Reach (such as Divide Creek, Zig-Zag Creek, Wolf Creek, Deep Creek, Getta Creek, Tryon Creek, Camp Creek, Sommers Creek, Kirby Creek, Kirkwood Creek, Temperance Creek, Sheep Creek, Rush Creek, Sluice Creek, Bernard Creek, Hat Creek, Saddle Creek, Three Creeks, Granite Creek, Wild Sheep Creek, Battle Creek, Brush Creek). If the earliest migrating adult fall Chinook salmon were to be immediately transported to and remain in the warmest water of the upper Hells Canyon Reach of the Snake River, they might be exposed to temperatures ≥19.0°C for about 45 days (with a maximum mean temperature of about 22.0°C). This is similar to what fish used by Jensen et al. (2006) experienced, and they did not report a delay in gamete maturation, or in quality of gametes. However, it is unknown whether adult fall Chinook salmon tend to immediately move into the upper Hells Canyon Reach, or the extent to which they may use cool water refuges mentioned above.

With respect to delay of the actual spawning activity, there is evidence that a shift toward earlier spawning might be feasible if the river corridor could be cooled substantially. However, it would likely be very difficult to cool the river enough to make a reasonable shift in spawn timing. Data from 16 years of spawning surveys in the Snake River indicates that initial spawning is not consistently initiated because of either photo period or water temperature (Table 3). In the upper Hells Canyon Reach, the earliest spawning was observed as early as 9 October (at a weekly mean temperature as high as 19.1°C), and as late as 11 November (at a weekly mean temperature as low as 12.5°C). This presents a difference in timing of four weeks and a 6.5°C difference in temperature. In the lower Hells Canyon Reach (LHC), spawning was observed as early as 9 October (at a weekly mean temperature as high as 17.9°C), and as late as 5 November (at a weekly mean temperature as low as 12.7°C). Again, this is a four week difference in timing and a 5.0°C difference in temperature.

Table 3. Timing of first observed spawning and mean water temperature (°C) during 7 days prior to observation for both the Upper Hells Canyon Reach of the Snake River (UHC) and the Lower Hells Canyon Reach of the Snake River (LHC).

Year	First Observed Spawning UHC	Mean Water Temp. (°C) During 7 Days Previous UHC	First Observed Spawning UHC	Mean Water Temp. (°C) During 7 Days Previous LHC
1991	11 Nov	12.5	28 Oct	13.6
1992	05 Nov	14.5	05 Nov	12.7
1993	01 Nov	14.1	25 Oct	13.9
1994	24 Oct	15.9	01 Nov	12.7
1995	23 Oct	15.0	30 Oct	11.2
1996	21 Oct	15.8	28 Oct	11.5
1997	27 Oct	13.5	20 Oct	14.1
1998	26 Oct	14.5	26 Oct	12.1
1999	18 Oct	16.1	18 Oct	15.1
2000	09 Oct	17.3	23 Oct	13.6
2001	09 Oct	19.1	09 Oct	17.9
2002	21 Oct	15.7	21 Oct	13.7
2003	20 Oct	17.5	27 Oct	14.7
2004	25 Oct	16.5	18 Oct	15.7
2005	18 Oct	16.6	18 Oct	14.9
2006	23 Oct	15.8	23 Oct	13.6

During recent years (1998-2006), spawning within the Clearwater River has tended to begin approximately two weeks earlier than in the Snake River (range between 4 to 29 days earlier; Table 4). The initiation of spawning in the Clearwater River has been observed as early as 23 September, and as late as 12 October, a difference of about three weeks in timing. From available data, it appears that when spawning occurs within the Clearwater River, the mean weekly water temperature for the seven days prior to when the first redds are observed has been between about 9.4-13.5°C.

Table 4. Timing of first observed spawning and mean water temperature (°C) during 7 days prior to observation (measured at both Lewiston and Peck) for fall Chinook salmon in the Clearwater River.

Year	First Observed Spawning CLRWTR	Mean Water Temp. (°C) During 7 Days Previous (Lewiston)	Mean Water Temp. (°C) During 7 Days Previous (Peck)
1998	12 Oct	No data	No data
1999	05 Oct	No data	No data
2000	05 Oct	No data	No data
2001	03 Oct	No data	No data
2002	01 Oct	12.3	No data
2003	23 Sep	13.5	11.6
2004	28 Sep	13.4	11.3
2005	10 Oct	No data	9.4
2006	25 Sep	13.1	11.9

During the years (1992-2006), spawning within the Grande Ronde River, has tended to begin three days earlier than in the Snake River (range between 1 day later and 14 days earlier; Table 5). The first observed spawning in the Grande Ronde River has occurred as early as 8 October to as late as 26 October, a difference of about three weeks in timing. From available data, the mean weekly water temperature for the seven days prior to when the first redds are observed within the Grande Ronde River has been between 7.6-13.3°C.

Table 5. Timing of first observed spawning and mean water temperature (°C) during 7 days prior to observation for fall Chinook salmon in the Grande Ronde River.

Year	First Observed Spawning GRonde	Mean Water Temp. (°C) During 7 Days Previous
1992	23 Oct	11.0
1993	25 Oct	9.9
1994	24 Oct	No data
1995	23 Oct	No data
1996	21 Oct	No data
1997	20 Oct	7.6
1998	26 Oct	8.6
1999	11 Oct	No data
2000	16 Oct	11.5
2001	09 Oct	12.5
2002	21 Oct	9.1
2003	08 Oct	No data
2004	12 Oct	13.3
2005	11 Oct	12.3
2006	24 Oct	9.7

Generally, the initiation of spawning in the upper Hells Canyon Reach of the Snake River occurs by about 23 October, at a mean water temperature of 15.7°C. The initiation of spawning in the lower Hells Canyon Reach of the Snake River occurs by about 24 October, at a water temperature of 13.8°C. As an additional note, during 12 of the 16 years of data, spawning began in the upper Hells Canyon Reach either before or on the same date as it did in the lower Hells Canyon Reach, when water temperatures averaged 2.5°C warmer than in the lower reach. If spawn time were solely temperature related, the question as to why fish in the lower reach do not always initiate spawning at an earlier date when water temperatures are cooler would remain. Spawning within the Grande Ronde River tends to begin by about 18 October, at a water temperature averaging 10.6°C. Also, spawning within the Clearwater has tended to begin by about 1 October, at a water temperature that averages somewhere between 11.1-13.1°C. It is further confounding that fish within the Grande Ronde River tend to begin spawning almost three weeks later than fish in the Clearwater River, but at water temperatures that are somewhere between 1-3°C cooler. It is not evident that cooler water in the Grande Ronde River leads to earlier spawning (compared with the Clearwater River).

Based on this review, it is the conclusion of IPC; that there is no evidence that spawn timing has been greatly altered in the Snake River as a result of the shift in the thermal regime by the Hells Canyon Complex. This is based on comparisons of pre-HCC spawn time distribution to that of the present-day Hells Canyon spawn time distribution. Further, spawn timing appears to be strongly associated with a declining thermal regime and likely other environmental cues that are consistent regardless of water temperature, such as photoperiod, rather than a specific water temperature.

4.6 Incubation Survival

The primary questions in this area of inquiry are how water temperature may affect the final survival of incubating embryos of Snake River fall Chinook salmon, and how temperature may influence the expression of an ocean-type life history of these fish. There appear to be many studies from which to draw inference to these questions, however many of the following factors influence the usefulness of these studies relative to these specific questions. These factors include the following four considerations.

1) Many of these studies pertain to other races or species of Pacific salmon. Fall Chinook salmon is the only Pacific salmon that spawns during the fall (October through December) within the mainstem of the Snake River downstream of the Hells Canyon Dam. As such, the spawning and incubation requirements of other salmonid species, and to some extent other Chinook salmon races, are not relevant. Generally there are small differences in thermal responses among stocks and these differences increase from races, subspecies to species and then families of fishes (McCullough et al. 2001). Genetic variation exists within Chinook salmon and other salmonids of the Pacific Northwest, as indicated in classification diagrams constructed by the National Marine Fisheries Service (McCullough et al. 2001). It is clear that based on ***constant*** temperature studies, different

species exhibit differential upper and lower threshold temperatures, relative to survival, for incubating embryos. For example sockeye salmon (13.5° C) and Chinook salmon (14.9° C) have been reported to have different upper threshold temperatures for incubating embryos (Combs and Burrows 1957, Combs 1965). ***Constant*** temperature studies of embryo survival (such as Murray and McPhail 1988) and investigations of temperature and its effect on embryonic developmental rate and emergence timing (such as Beacham and Murray 1990) have shown that the various species of anadromous Pacific salmon are **"… adapted to different spawning times and temperatures, and thus indirectly adapted to specific incubation temperatures …"**. For example, Murray and McPhail (1988) demonstrate that chum salmon and Chinook salmon have considerably greater embryo survival through emergence at warmer ***constant*** test temperatures (50% and 46%, respectively), than do other Pacific salmon species (pink salmon – 22%, coho salmon – 11%, and sockeye salmon– 8%). Finally, while Beacham and Withler (1991) showed that final mortality of ocean- and stream-type Chinook salmon juveniles, based on ***constant*** elevated water temperature, were similar, the ocean-type progeny survived for a significantly longer period of time at elevated temperatures. Those authors speculated that ocean-type Chinook salmon are better adapted to warmer water conditions.

2.) Given the best possible scenario, the most instructional data concerning incubation survival relative to thermal conditions would take into account the thermal conditions that the adults were exposed to prior to spawning, especially during the pre-spawn gamete maturation period. Several studies (presented in section 4.3 above) are often cited for confirmation of the negative effect of elevated water temperature during the adult pre-spawn period on gamete viability and ultimately embryo survival (see McCullough et al. 2001). Upon further review, it is evident that there has been very little research in this area of pre-spawn gamete viability and there is no clear conclusion as to the effect of elevated pre-spawn temperatures on gamete viability. It is apparent that the adults from which gametes were obtained for these studies were either exposed to generally cool hatchery water conditions, or their thermal history is unknown (Johnson and Brice 1953, Donaldson 1955, Olson and Foster 1955, Hinze et al. 1956, Seymour 1956, Combs and Burrows 1957, Seymour 1959, Rice 1960, Combs 1965, Jewett 1970, Olson et al. 1970, Healey 1979, Garling and Masterson 1985, Neitzel and Becker 1985, Murray and Beacham 1987, Murray and McPhail 1988, Beacham and Murray 1989, Geist et al. 2006). It is evident from many of these studies that there is significant difficulty in maintaining such large adult fish in crowded, captive conditions for extended periods of time prior to spawning. Most of the reports cited in the EPA Region 10 review to support their thermal criteria for incubating salmonid embryos faced these types of problems when including holding adult Chinook salmon (McCullough 1999, McCullough et al. 2001).

3.) Throughout the available literature concerning Chinook salmon incubation survival, it is apparent that test embryos have been maintained through several various stages, including eyed (Johnson and Brice 1953, Rice 1960), hatch (Donaldson 1955, Seymour 1956, Combs and Burrows 1957, Seymour 1959), emergence (Garling and Masterson 1985, Neitzel and Becker 1985, Murray and Beacham 1987, Murray and McPhail 1988, Beacham and Murray 1989, Geist et al. 2006), and fry feeding (Johnson and Brice 1953, Donaldson 1955, Olson and Foster 1955, Hinze et al. 1956, Hinze 1959, Jewett 1970, Jewett and Menchen 1970, Olson et al. 1970, Healey 1979). Survival through at least the emergence life stage (the end of what would constitute incubation) is more meaningful to assess the influence of water temperature through incubation.

4.) When reviewing the many studies available on how water temperature affects the survival/mortality of incubating Chinook salmon embryos (through any developmental stage), it becomes apparent that the type of thermal regime that the test organisms have been exposed to is quite variable and may not represent natural thermal regimes. Two basic types of studies (with many variants of exposures) are most prevalent in the literature: constant or variable/natural. EPA documents reviewed and reported on incubation survival and mortality data from both constant and variable thermal experiments, but seemed to rely most on constant temperature analyses to defend their regional guidance. The EPA concluded that **"As discussed previously in this paper, constant laboratory test temperatures of 48.2-50°F (9-10°C) should be considered roughly equivalent to naturally fluctuating stream temperatures with daily maximums of 51.8-53.6°F (11-12°C)"** (McCullough et al. 2001). There is only a very general, brief discussion of this conclusion and it does not appear to be sufficiently supported to justify its use. The derivation of this relationship appears to be based on growth tests of juveniles (usually rainbow trout) and not survival/mortality experiments concerned with egg incubation. More importantly, those studies that tend to indicate that constant temperature regimes were similar to fluctuating regimes stemmed from data that actually varied the test temperature cyclically around a "mean, constant" temperature rather than a declining thermal regime. The data from those experiments have little to do with a naturally declining thermal regime most commonly present in large river systems and are not properly applicable in the context of a natural regime. While constant temperature experiments have their use, mostly for determining how hatchery production can be more efficient, they are not particularly useful in defining how developing embryos might be affected in a natural habitat, such as in the Snake River. This becomes obvious if researchers were to plot the thermal exposure conditions that are normally observed within the Snake River as well as what have been used in laboratory constant exposure studies, such as Seymour (1956; Figure 10).

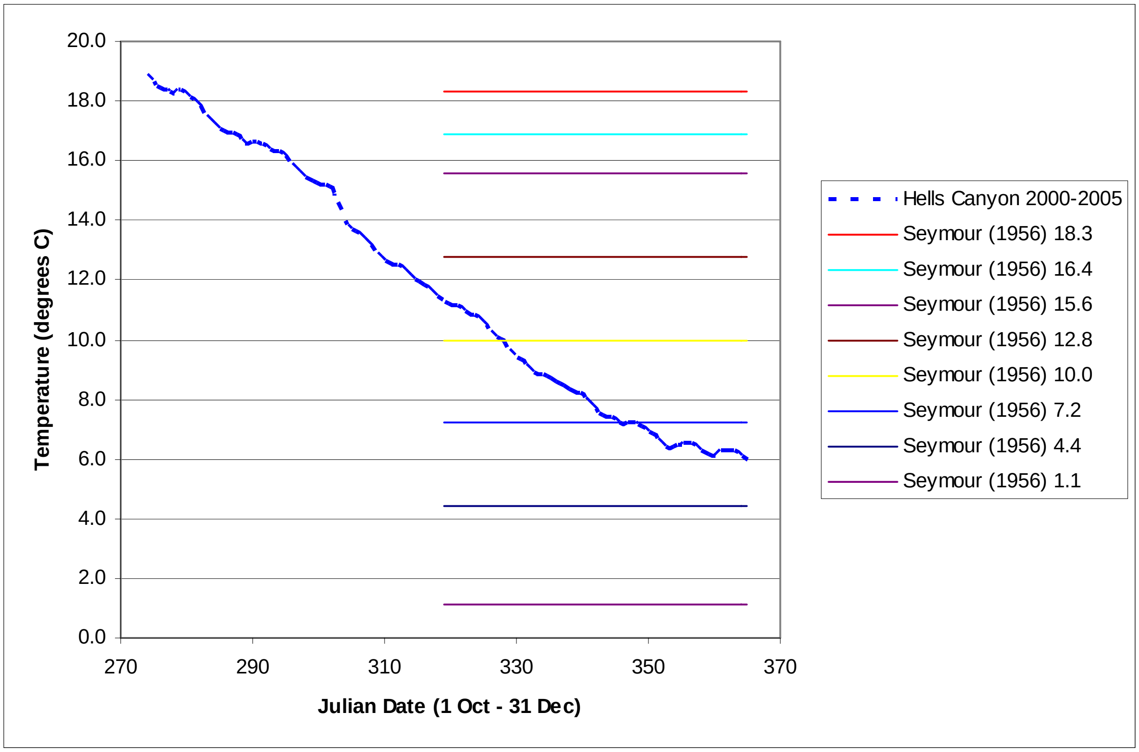

Figure 10. Comparison of maximum daily water temperature reported for the Mokelumne River (1967) and the mean daily maximum temperature in the upper Hells Canyon Reach of the Snake River (2000-2005)

However, constant temperature experiments can be useful as a basis for estimating how long incubating embryos can be maintained at specific temperatures prior to succumbing to excessive mortality. For example, by examining results from several studies (using constant and variable temperature regimes), it is evident that above about 13.0° C, the survival of Chinook salmon embryos may be negatively affected based on a function that includes how high the water temperature is, the dissolved oxygen level present, and the amount of time that the embryos are exposed to specific conditions (Healey 1979). Longer exposure to higher water temperature and lower dissolved oxygen will eventually result in increased mortality of incubating Chinook salmon embryos. Also, while conditions of warmer water temperature may not necessarily result in increased mortality, they may result in fry being smaller (both in length and weight) than individuals incubated in a cooler environment (Donaldson 1955, Heming 1982). However, there is a trade-off that occurs across the continuum of "warmer temperature – smaller fry" through "cooler temperature – larger fry." First of all, the difference in size, while often statistically significant, is generally quite small – often a few millimeters in length or a few milligrams of weight (Donaldson 1955, Olson and Foster 1955, Heming 1982). This is often suggested to result in a reduced survival opportunity for the smaller fry (Donaldson 1955). However, smaller fry produced from slightly warmer conditions will tend to hatch, emerge, and begin feeding earlier (Olson and Foster 1955, Heming 1982, Heming et al. 1982). This has also been suggested to provide an increased survival opportunity (Heming 1982). As well, fry that begin feeding at smaller size, but at an earlier time, will tend to grow as large, or larger, than later emerging fry, thus compensating for their smaller size at emergence (Olson and Foster 1955).

The following sections review literature often cited to support the effect of temperature on incubation success and attempt to evaluate the applicability of these studies to Snake River fall Chinook salmon based on the above four factors and then will synthesize the findings from these studies to make conclusions regarding Snake River fall Chinook salmon and incubation. Each review makes note of what stock was studied, whether notes concerning the disposition of adults were recorded, what the thermal exposure of the embryos was, to what stage of development the embryos were maintained, and the final survival/mortality data that was provided. A few of the relevant studies have previously been reviewed earlier in this paper. Those works will be noted, but will not be covered a second time.

4.6.1 Egg Incubation Temperatures

Johnson and Brice (1953)

The impetus for this study was based on depressed survival of Chinook salmon embryos at the Dorena Hatchery, in Oregon. The investigators hoped to learn whether the depressed survival was due to toxic water conditions, elevated incubation temperatures, or handling conditions. Both spring and fall stocks of Chinook salmon were tested. Experiments were conducted over the course of two incubation seasons, 1951-1952 and 1952-1953. It appears that the fall Chinook salmon used in this study originated from two sources; during 1951-1952 adults were provided from Spring Creek Hatchery, and during 1952-1953 adults came from the Little White Salmon Hatchery. The first season of testing maintained some of the test lots through emergence and into the feeding stage; however, during the second season of tests all treatment lots were terminated at the eyed stage because the hatchery was at that time permanently closed. There were no notes or observations as to what conditions the adults during each season were exposed to prior to spawning.

During the first season of testing, fertilized embryos were subjected to various treatments. Fertilized eggs from several females were mixed together and were then split into single test lots. One lot of eggs (lot A) was spawned and maintained at the originating hatchery (Spring Creek). These eggs were to be used as the control group. Two egg lots were maintained for a brief period (approximately 2.5 hours) in sealed jars and were either kept at the originating hatchery (lot B) or were driven about before being returned to the originating hatchery (lot C). Eggs from these tests were maintained through the eyed stage, and results were used to determine if handling and transportation conditions led to increased mortality. Three other egg lots were also placed in sealed containers and driven to Dorena hatchery where they were exposed to three different thermal regimes. The thermal conditions used for exposures at Dorena hatchery included the following: coolest water available at the hatchery (lot D), cool water that was chilled even further by between 2.8 to 5.5° C (lot E), and the warmest water available at the hatchery (lot F).

Unfortunately, embryos from the fall Chinook salmon were not exposed to the warmest thermal conditions.

The results from the first season of study that are most important come from lots A, D, and E. Unfortunately, no thermal data was provided for lot A; however, mortality was reported as 12.1%. Embryos in lot D began incubation at about 12.8° C, increased to a high of 15.6° C, and then declined to a low of about 7.0° C. These embryos remained at about 15.6° C for approximately 12 days. Mortality for this group was reported as 17.5%. The thermal regime for Lot E began at a temperature of 10.0° C, increased to a high of 12.8° C, and then declined to a low of about 7.0° C. Mortality for this group was reported as 9.5%. At first glance, it might be deduced that the warmer thermal regime of lot D resulted in significantly higher mortality than what was observed for the control lot A, or the coolest lot E. However, because no replicates for each thermal exposure were maintained, it was not possible to assess variability or to test for statistical differences among the various test groups. The embryos in lot D were also subjected to a warm temperature (15.6° C) for a relatively long time period (12 days). This would likely have a negative effect on embryo survival. Also, because eggs from several females were mixed together, it was impossible to assess variability due to parental lineage.

During the second season of tests, embryos were obtained from several females on 24 September and mixed together. Three lots of eggs were subjected to different thermal conditions and were maintained through the eyed stage (12 November); at that point the tests were terminated. The first group (lot A) was again spawned and maintained under conditions present at the originating hatchery (Little White Salmon). A second group (lot D) was spawned at Little White Salmon hatchery, transported to Dorena hatchery in sealed jars, and then maintained in the coolest water available at the hatchery. A third group (lot E) was spawned and transported in a similar fashion to lot D, but was maintained at Dorena hatchery under thermal conditions that were about 12.0° C cooler than the ambient environment.

Again, no thermal data was presented during the second season for egg lot A (the control group). However, mortality, through the eyed stage, was recorded as 3.7%. Egg lot D had 100% mortality through the eyed stage. However, it was noted that these embryos were exposed to a ***minimum*** temperature of 18.3° C. Egg lot E suffered a mortality of 3.6%, and it was noted that the highest temperature that these embryos were exposed to was 11.9° C. No replicates were maintained, and as such it was again impossible to assess variability and to test for differences among groups.

This early study initially had a very good overall design, and could have resulted in very insightful data concerning the effects of water temperature on incubation survival. However, because no replicates were maintained throughout any of the tests, no thermal data was presented for the control groups, and the second season was terminated early, the data are of very little use. There were no observations that can provide valuable data on variability, nor can tests for statistical differences be conducted. The results from the first season tend to indicate that water temperatures as high as 15.6° C for as long as 12 days (lot D) can result in elevated mortality; however, this is not confirmed statistically.

The authors are likely correct in their final conclusions, that high water temperature at Dorena Hatchery resulted in excessive embryo mortality at that hatchery, and that temperatures less than about 12.0° C can result in good survival of Chinook salmon embryos. It is also quite obvious that maintaining Chinook salmon embryos at temperatures above 18.0° C ***for as long as 49 days*** (lot D during the second season) will result in 100% mortality.

Finally, the thermal exposure regimes used in this study, and that resulted in the highest mortalities, are not similar or typical to what occurs within the Snake River during the spawning and incubation period of fall Chinook salmon. As with some of the studies discussed earlier concerning the effects from pre-spawn thermal conditions on embryo survival (Jewett 1970 and Jewett and Menchen 1970), the temperature of the Dorena Hatchery tests increased through early incubation before cooling. Also, test embryos tended to remain at higher temperatures for a long period of time (12 days at 15.6 ° C or 49 days at about 18.0° C). While the Dorena Hatchery temperature conditions may have been "normal" for that system, they are certainly not representative of what occurs within the Snake River historically or presently.

Donaldson (1955)

The data provided from this study were the result of two seasons of tests. The tests were designed to determine how elevated water temperature during early incubation of Chinook salmon affected survival. Adults from which gametes were collected were obtained from Green River Hatchery, Washington, a fall-run stock from nearby Soos Creek. Prior to spawning, adults were maintained at the hatchery, and held at approximately 13.6° C. During each season, groups of test embryos were maintained at various constant temperatures until attaining specific developmental stages. At the completion of each predetermined stage, test lots were transferred to an optimum, control temperature bath. During each season, the actual test temperatures were different, and ranged from 16.7 to 19.4° C. For all experiments the author intended to maintain test organisms through the feeding stage; however, complications with the water filtration system during the first season resulted in termination of the experiment just after the hatch stage, and bacterial invasion during the second season made it difficult to successfully maintain the control groups.

During the first season, after fertilization all embryos were mixed. Embryos were initially maintained at three test temperatures (16.7, 18.3, and 19.4° C), and a control temperature (11.8° C). Each temperature treatment contained five test lots of 250 eggs each. One lot within each treatment temperature was kept at the initial test temperature throughout the experiment. The four other test lots within each treatment were maintained to a specific developmental stage (100, 200, 350, and 500 Fahrenheit thermal units) before being transferred to the control temperature. Final mortality and abnormalities were noted for each test lot. This design prevented replication of test results within each of the test temperatures, limiting statistical comparisons among treatments.

The first season's tests were complicated due to water filter failures. Because of this, the tests were concluded early, just post-hatch. The results from the first season were not particularly useful, but did indicate that mortality at exposure temperatures ≥18.3° C were greater than what was observed for the lower test temperature (16.7° C) or for the control groups.

During the second season, embryos from two females were used, and were kept separate in order to evaluate responses due to parental lineage. The basic design of the experiment was similar to that of the first season, except that the lower test temperature of 16.7° C was increased to 17.2° C, and the control temperature was maintained at approximately 12.8° C. Finally, the test embryos were able to be kept through the initial feeding stage. While filtration complications were eliminated during the second season, severe bacterial growth made it difficult to successfully maintain the control lots.

Eggs from female two had much higher mortality within each temperature treatment, including the control. For example, total mortality, through feeding, for eggs from female one was about 20%, while for female two it was 99%. Within all treatments, the shortest exposure time did not result in elevated mortalities during the pre-hatch period. However, as exposure time within each treatment was increased, total mortalities also increased. As well, it was noted that while warmer exposure temperatures resulted in faster development, the resultant fry tended to be smaller than control cohorts. Finally, the data tended to point out that mortality was higher within all groups (test and control) during specific developmental stages (during the hatch period, and during the transition from final yolk absorption to active feeding).

The tests for this study were designed to result in increased mortalities; this is an important note to keep in mind. While this study does provide some useful information, again, it was impossible to statistically analyze the data as only one lot of eggs was exposed to specific treatments. For example, while there were five lots within any one temperature treatment, each lot was exposed over a different amount of time, thus no replicates were available for each treatment. The most useful information that can be derived from this work is that mortality can be elevated (even under the most optimum thermal conditions) during specific developmental phases. Also, it is noteworthy that developmental rates can be accelerated at warmer temperatures, and that embryos that have been exposed to warmer temperatures can be smaller than cohorts exposed to cooler conditions.

Olson and Foster (1955)

This experiment was undertaken due to a concern that warming of the water during early incubation of Chinook salmon embryos in the Columbia River, due to heated power plant effluent, might result in elevated mortalities. Data were collected through a single season of incubation. Gametes for the test were collected from a fall-run Chinook stock of the middle Columbia River (Hanford Reach). Adults were collected from the river and spawned in the field on 26 October. Unfortunately, adult pre-spawn exposure temperatures are unknown. However, recent data for that reach indicates that from 1

October through 26 October water temperatures tend to decline, and to range from 17.9 to 14.8° C (mean of data from the Columbia River DART web page, 1995-2006). After initial spawning, test embryos were placed and maintained within five different temperature treatment groups. While each treatment temperature was different, they all followed a declining, then increasing regime pattern that is seasonally typical for that river. The five temperature treatments began at 11.6, 13.8, 15.0, 16.1, and 18.4° C. These initial test temperatures were also the highest temperatures that embryos were exposed to during their development. The temperature treatment that began at 13.8° C was noted as following a thermal regime that was typical for the river reach in question. Embryos were maintained well into the fry feeding stage. After feeding began, samples from each treatment were removed and weighed on a two-week interval. Final mortalities were noted.

Olson and Foster (1955) were able to conduct some level of statistical analysis. The authors conclude that only in the highest test temperature of Lot E was mortality among eggs, fry, and fingerlings significantly greater (at the 5% level of probability) than what was observed in the control Lot B. Additionally, as will be shown later, the data from this study can be combined with that of a later test using the same fall-run Chinook stock and similar thermal treatment conditions (Olson et al. 1970), as well as results from Geist et al. (2006). By combining those data, one can assess variability and accomplish, and enhance the clarity of, statistical tests to determine significant differences.

This experiment was certainly a more realistic attempt to describe how elevated water temperature may affect the survival or mortality of incubating fall Chinook salmon embryos exposed to a natural thermal pattern. Adults were collected and spawned in the field, and as such were exposed to natural thermal conditions present in the Hanford Reach of the Columbia River just prior to spawning. Each temperature treatment exposure was different, and they all followed a natural thermal pattern. The final mortality data was statistically evaluated indicating that mortality was similar at initial temperatures between 11.6 and 16.1° C (range of 7.8 to 16.1%), but highly elevated (79.0%) at an initial temperature of 18.4° C (Table 6). Also, data from this experiment validated that warmer temperature during incubation led to faster development and earlier emergence and slightly smaller fry upon emergence. However, the fry that emerged earlier and smaller began feeding earlier and grew faster than later emerging, larger cohorts.

Table 6. Final mortality data (through feeding stage) for incubating Hanford Reach fall Chinook salmon as a result of initial exposure temperature.

Initial Exposure Temperature (° C)	Final Mortality (%)
11.6	7.8
13.8	16.1
15.0	10.1
16.1	10.4
18.4	79.0

<u>Hinze et al. (1956)</u>

This report was previously reviewed in the section concerning adult pre-spawn conditions.

<u>Seymour (1956)</u>

This work was undertaken in order to determine how temperature affects development rate, as well as how temperature might induce "abnormalities". A series of three experiments were conducted over three incubation seasons. Several different stocks of Chinook were used. During the first two seasons of study, gametes were obtained from Green River fall Chinook salmon. During the third season of study, four different Chinook stocks were used: Skagit River (spring Chinook), Entiat River (fall Chinook), Sacramento River (fall Chinook), and Green River (fall Chinook). The environment that adults were exposed to prior to spawning was not reported. The temperature treatments that embryos were exposed to during the first two seasons were constant, whereas the exposure treatments of the third season followed a more natural, seasonal thermal pattern, declining through the winter and increasing through the spring. The survival data are somewhat sketchy, and while it is not directly stated in the text of the work, it is evident that these data are only presented through the hatch stage.

During the first season embryos were maintained at eight different constant thermal conditions (1.1, 4.4, 7.2, 10.0, 12.8, 15.6, 16.9, and 18.3° C). During the second season, embryos were maintained at seven different constant thermal conditions (7.2, 10.0, 12.8, 14.7, 15.6, 16.9, 18.3, and 19.7° C). The results from the first two seasons indicated that mortality through the hatch stage was low and similar (≤10%) for all egg lots incubated at constant temperatures less than 15.6° C. Embryo groups incubated at constant temperatures of 15.6° C and higher had significantly greater mortality. It should be noted that during the second season of this study, a filter problem occurred, and substantial mortality occurred throughout all test groups. Also, while few actual numbers were recorded, the following information was reported:

1. Eggs incubated at constant temperatures of 1.1 and ≥18.3° C had 100% mortality.
2. Eggs incubated at constant temperatures 15.6 and 16.9° C had high mortality prior to hatching, and then total mortality during the yolk absorption period.
3. Eggs incubated at constant temperatures of 12.8 and 14.2° C had low mortality prior to hatching, and then high mortality during the yolk absorption period.
4. Eggs incubated at constant temperatures of 4.4, 7.2, and 10.0° C had low mortality throughout all developmental stages.

During the third season, initial test treatments began at the following temperatures: 7.2, 10.0, 12.8, 15.6, and 18.3° C. Each treatment group had the temperature reduced by 0.5° C every five days until they reached 1.1° C. Each treatment group was then maintained at this low temperature for 20 days, at which time the temperature was then increased by 0.5° C every five days. One lot of eggs was kept as a control and was maintained at a constant 12.2° C throughout the third season of tests. The author reported low mortality (generally less than 5%) through the hatch period for all treatment groups incubated under a “natural” thermal regime when initial temperature was ≤15.6° C. The author also noted that test groups that resulted in high mortality through the hatch stage were exposed to temperatures ≥17.0° C for at least 15 days.

This very involved study was not specifically designed to provide data on incubation mortality or survival, and as such it does not provide very useful data on that subject. However, a few noteworthy observations and conclusions were made based on the results from the three seasons of work. The first was that survival/mortality results (at least through the hatch stage) were different based on whether the embryos were subjected to constant or “naturally variable” temperature conditions. If embryos initially began incubation under the same elevated temperature as high as 15.6° C, those kept under constant conditions suffered high mortality through the hatch stage, while those that experienced a more normal thermal regime had very low mortality through the hatch stage. This information is very important, as it indicates that survival/mortality data based on constant temperature studies may not represent what occurs in a naturally variable environment. A second observation stemmed from a few of the control egg groups being accidentally maintained at very low dissolved oxygen (≤3.0 mg/L) levels for 21 days. Those embryos suffered very low mortality (less than 10%), indicating that low dissolved oxygen during early incubation (prior to hatching) does not result in increased mortality. Finally, it was observed that under constant thermal conditions, high and low temperatures resulted in increased abnormalities (increased number of vertebrae), while embryos subjected to a natural thermal regime did not suffer from increased abnormalities, even when the initial exposure temperature was elevated. All of these observations indicate that exposing Chinook salmon embryos to constant thermal conditions during incubation produces very different results compared to exposure to more natural, variable thermal conditions.

Combs and Burrows (1957)

These authors reported on a series of constant temperature tests that were conducted over a period of three years. These experiments were conducted to determine more efficient methods for managing hatchery environs. Eggs were obtained from Entiat and Skagit River Chinook stocks; however, it was not stated whether these were spring, summer, or fall-run stocks. No records were provided as to the thermal conditions that the adults were exposed to prior to spawning. Embryos were maintained at several constant temperatures, including: 1.7, 3.1, 4.4, 5.8, 7.2, 10.0, 12.8, 14.2, and 15.6° C. Embryos were only maintained through the hatch stage.

The authors observed that at a constant temperature of 1.7° C 100% mortality occurred. Based on their results, they estimated that the lower threshold temperature was 5.1° C, and that the upper threshold temperature was 14.9° C. They also noted that as long as early incubation temperatures were above 4.4° C, then embryos could successfully tolerate colder temperatures during later stages of incubation. Finally, the authors wanted to make certain that future researchers understood that the results from this work were only valid for describing development under constant temperature conditions; they noted:

"The range of incubating temperatures between 42.5 and 57.5 degrees F, established by these experiments as the range for normal development, applies only to constant temperatures".

<u>Hinze (1959)</u>

This report was previously reviewed in the section concerning adult pre-spawn conditions.

<u>Seymour (1959)</u>

This paper is derived from data previously reported in Seymour (1956), and as such provides no additional information.

<u>Rice (1960)</u>

This report was previously reviewed in the section concerning adult pre-spawn conditions.

<u>Combs (1965)</u>

This paper reports on the effects of constant temperatures on the survival/mortality of incubating sockeye and Chinook salmon embryos. The tests conducted were mostly done on sockeye embryos, but a connection was made to earlier work done on Chinook salmon by Combs and Burrows (1957). The thermal conditions to which adults were exposed to prior to spawning were not described, nor was it specifically stated to what stage the embryos were maintained.

The author determined that the lower threshold temperature of sockeye salmon was approximately 5.1° C, and that the upper threshold temperature was 13.5° C. It was concluded that, citing results from Combs and Burrows (1957), sockeye were more tolerant of colder temperatures and less tolerant of warmer temperatures when compared to Chinook salmon. This is an important point, indicating that different salmon species have different thermal tolerances. Also, the author reiterated that the results from these experiments were based on constant temperature, and should not be used to estimate what might occur in a natural environment: **"We emphasize that the results of the threshold temperature experiments were derived from constant incubating temperatures. The conditions imposed upon the sockeye salmon eggs in these tests would rarely be duplicated in nature or in artificial propagation procedures"**.

<u>Jewett (1970)</u>

This report was previously reviewed in the section concerning adult pre-spawn conditions.

<u>Jewett and Menchen (1970)</u>

This report was previously reviewed in the section concerning adult pre-spawn conditions.

Olson et al. (1970)

This study was a later expansion on what was previously done by Olson and Foster (1955), and is a more detailed description of the methods and results that were reported on by Olson and Nakatani (1968). The experimental procedure was designed to test how elevated water temperatures during early incubation development might affect final survival/mortality of Chinook salmon embryos. The Chinook stock used for this study was the fall-run stock of the Hanford Reach of the Columbia River. Adult salmon were spawned at the Priest Rapids hatchery; however, no data is reported as to the thermal conditions that adults were exposed to prior to spawning. Gametes were collected from single female/male pairs at four times during the spawning season: 30 October, 14 November, 23 November, and 8 December. At the time of spawning, groups of embryos were randomly placed in one of seven thermal environments. One of the embryo groups was always placed into conditions that mimicked natural Columbia River water temperatures. The other groups included conditions that were 2.0, 4.0, and 6.0° F warmer than ambient river conditions, and 2.0, 4.0, and 6.0° F cooler than ambient river conditions. Dissolved oxygen was maintained near saturation. Test organisms were maintained into the fry feeding stage.

The resulting data indicated several interesting points. Later spawned eggs, from adults acclimated to cooler conditions, were able to tolerate a larger thermal increment away from the normal river temperature. Very warm conditions during early incubation generally resulted in increased mortality. These authors noted that delayed mortality, resulting from early exposure to high temperature, tended to occur in later developmental stages. The most critical period where delayed mortality tended to occur was during the shift from yolk absorption to active feeding. Increased temperature tended to accelerate development and growth of embryos. In contrast to other study results, this work indicated that, at the same accumulated thermal units, embryos exposed to warmer temperatures tended to be heavier than their cohorts exposed to cooler temperatures. Finally, the authors concluded that, given a naturally variable thermal regime, increased mortality tended to occur when initial water temperature during incubation was above about 16.0° C. However, a closer examination of the data from this study indicates that the initial exposure temperatures were not the highest that embryos were subjected to. Based on the data provided, it appears that increased mortality actually resulted at temperatures that at some point during early incubation exceeded 16.5° C. As with Olson and Foster (1955), the results from this study are more relevant to how water temperature affects Chinook salmon embryo survival than are any constant temperature experiments.

As with most all other earlier experiments, no replicates were maintained for any single exposure temperature. Therefore, variance could not be estimated, nor could statistical tests for differences be conducted. However, the data from this experiment can be combined with information from Olson and Foster (1955), as well as Geist et al. (2006), to provide a very clear description of how, given a naturally variable thermal regime, elevated water temperature during early incubation may affect Chinook salmon embryo survival. This analysis, which shows increased mortality of incubating fall Chinook salmon generally occuring at water temperatures > 16.5° C, will follow shortly (section 4.6.2).

Healey (1979)

This is another study conducted on Chinook salmon embryos designed to aid managers in determining how increased water temperature during early incubation may affect final survival of fry. The fish used for this study were from a fall-run stock of the Sacramento River, California. Tests were conducted at Coleman Hatchery near Anderson, California. There was no description as to the disposition of adults prior to obtaining fertilized gametes. The actual experiment was designed to test for egg and fry survival after exposure to various thermal regimes. Eggs were obtained on three different dates; 24 September, 22 October, and 9 November. After fertilization, eggs were mixed and roughly equal groups were maintained in three different thermal regimes; cold, cool, and warm conditions. Mortalities were recorded through at least the early stage of fry feeding.

The results from this study should be examined very carefully. Each group of eggs maintained in the warm conditions had final mortalities ≥80%. This is not surprising, as all of these eggs were exposed to fairly constant water temperatures of 15.6 to 16.1° C from 31 October through 31 December, a period of approximately 60 days. The only other group of eggs to suffer excessive, elevated mortality was the 24 September group placed in the cool water treatment. This group had a final mortality of 31%; however, they were exposed to a constant water temperature of 15.6° C for 15 days. The next highest mortality was from the 24 September egg group that was placed in the cold water treatment. These eggs had a final mortality of 13%, and had been initially exposed to a water temperature of 15.6° C for 5 days. Unfortunately, as with all other studies, no replicates were maintained within any temperature treatment. Therefore, there was no possibility to test for statistical differences due to treatments. However, the data from the spawning of 24 September strongly suggest that final mortality is not so much due to the actual thermal exposure, but more to the length of time that embryos are exposed to an elevated water temperature (Figure 11).

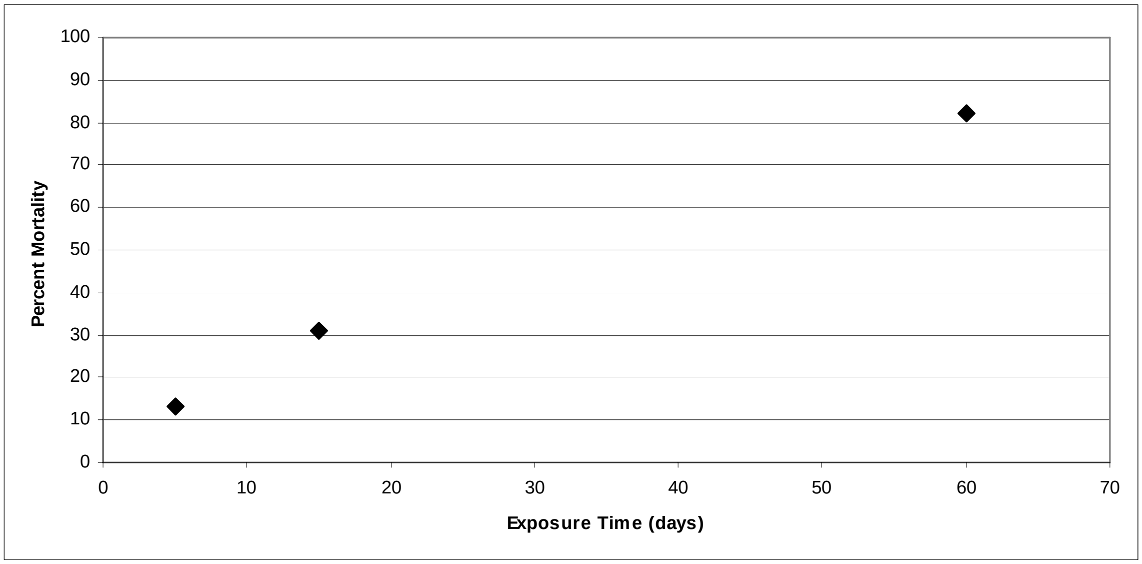

Figure 11. Percent mortality of Chinook salmon embryos dependant on exposure time (days) to water temperature of approximately 15.6 degrees C (data from Healey 1979).

While the thermal environment that embryos were exposed to in each of the three treatments were supposed to resemble a more normal, natural thermal regime, it is quite obvious that this was not the case. As mentioned above, embryos that were placed in the warm environment were exposed to water temperatures ≥15.6° C for approximately 60 days; this kind of exposure has never been observed in the Snake River. Also, early spawned embryos placed in the cool water treatment were exposed to water temperatures ≥15.6° C for approximately 15 days; again, this type of regime has never been observed in the Snake River.

<u>Heming (1982)</u>

This paper is sometimes used as a reference to support the proposition that elevated water temperature during incubation of Chinook salmon embryos results in increased mortality. However, the actual design of this study was to investigate how temperature during incubation might affect yolk conversion efficiency. The main aim of this work was to assist in developing methods that would make hatchery operations more streamlined and efficient. The stock used in the experiment was a fall-run Chinook from the Campbell River, British Columbia. There was no description as to the thermal environment that adults were exposed to prior to spawning. Fertilized eggs were maintained within four different constant temperature treatments (6.0, 8.0, 10.0, and 12.0° C). Four replicates were kept in each temperature treatment. Density of embryos was reduced at the time each group reached the eyed stage. After the hatch stage, a further reduced number of alevins from each temperature group were maintained in “artificial” redds in the lab; however, no replicates were kept during this later post-hatch developmental stage. Dissolved oxygen was maintained near saturation throughout the experiment. During the pre-hatch period, the water velocity through the incubation trays was roughly 790 cm/H.

The embryos that were placed in the "artificial" redds experienced intergravel water velocities estimated to be about 240 cm/H. Embryos were maintained through the emergence stage, but not into the fry feeding stage.

There was no specific data collected as to survival or mortality of incubating embryos. The author simply noted that survival to hatch and to emergence decreased slightly at the higher rearing temperature (constant 12.0° C); however, there was no statistical analysis performed to substantiate this observation. The development rate was increased at warmer temperatures, and emergence occurred earlier at warmer temperature. Emergence was noted to correspond with the time when maximum tissue weight was attained. It was observed that the maximum tissue weight was attained at the same development stage for all treatments; however, embryos from the warmer treatments tended to be both slightly less massive and shorter than cohorts exposed to cooler temperature treatments. It was also observed that embryos in the warmer treatments, while smaller than cohorts from cooler treatments, hatched, emerged, and began feeding earlier. The author concluded that this might actually provide territorial and survival advantages to the earlier emerging fish.

Garling and Masterson (1985)

This was another study conducted in order to help managers design more efficient hatchery operations. The question that was addressed was how maintaining Chinook salmon embryos under conditions of constant temperature might affect survival/mortality. Fish used for this study were an unknown origin Pacific Northwest fall-run stock transplanted to Lake Michigan. Constant temperature treatments included 9.9, 11.4, and 15.1° C. On a single date (13 October) 16 females were spawned, and their eggs were kept separate. Eggs were distributed so that several replicates from each female were placed into each temperature treatment. Test organisms were maintained through the emergence stage. Total survival/mortality data was not reported. Instead, survival was first recorded for all groups through the hatch period, and then a separate survival/mortality percentage was reported through emergence based on the number of living organisms present after hatch was completed.

Data from this experiment further supported that developmental rate was accelerated at warmer temperatures; hatch and emergence occurred earlier at warmer temperatures. Unfortunately, this study had several problems occur that make it difficult to assess the utility of the data. It was noted that a pump failure resulted in confounding survival/mortality data for the groups maintained at 15.1° C. It was also noted that eggs from two females had particularly high mortality within all temperature treatments; this was suggested to have occurred due to the gametes from those fish being singularly infertile. Finally, it was noted that pre-hatch survival was generally low (≤50%, with high variability) throughout all treatments; this was thought to have occurred due to poor handling procedures during early incubation. The manner in which the survival/mortality data were obtained and reported makes it difficult to make good use of the information presented in this report. However, it appears that mortality through hatch was similar in the two lower temperature treatments (9.9 and 11.4° C), and significantly higher in the highest temperature treatment (15.1° C). Finally, it should be reiterated that the results from this study are based on a constant temperature exposure treatment, something that does not occur naturally, especially in the Snake River.

Neitzel and Becker (1985)

This study was conducted to determine how short periods of warm and cold thermal shock, as well as levels of humidity, may affect incubation survival of Chinook salmon embryos. Of importance relative to this review are the results from the heat shock tests that were conducted. Gametes for this test were obtained from the Washington Department of Fisheries hatchery at Klickitat, Washington. There was no description as to the adult pre-spawn thermal conditions. Except for the periods of time when embryos were subjected to heat shock, developing embryos were maintained at a constant temperature of 10.0° C; test organisms were also maintained through the emergence stage. At specific developmental stages (60, 340, 570, and 810 accumulated Celsius thermal units – CTU), groups of embryos were subjected to different elevated temperatures (22.0, 23.5, 25.0, 26.5, and 28.0° C) for varying amounts of time (1, 2, 4, or 8 hour periods).

The tolerance of Chinook embryos to adverse conditions was noted to vary with magnitude and duration of exposure. Tolerance to shock did not appear to vary among progeny from different females. At temperatures as high as 22.0° C few mortalities were observed. Cleavage eggs (≈60 CTU) exposed to 22.0° C for as long as eight hours suffered relatively little mortality through emergence. However, for all exposure times at temperatures ≥23.5° C cleavage eggs suffered significant mortality. Embryos (≈340 CTU) could withstand exposure to temperatures as high as 25.0° C for all time treatments without suffering excessive mortality through emergence. However, for all exposure times at temperatures ≥26.5° C embryos suffered significant mortality. For all time treatments, eleutheroembryos (≈570 CTU) were observed to tolerate temperatures as high as 22.0° C with virtually no mortality occurring through emergence. At higher temperatures, and for all time treatments, eleutheroembryos suffered very high mortality. Exposure tests for pre-emergent alevins (≈810 CTU) produced results that were basically identical to those for eleutheroembryos.

Murray and Beacham (1987)

The variations of thermal conditions that embryos were exposed to during this study are somewhat arbitrary, and make very little sense; they do not represent what occurs in either a hatchery or in a natural river environment. The fish used for this study originated from the Harrison River, British Columbia; there is no direct note as to whether they were a spring, summer, or fall-run stock. However, based of the date of gamete collection (25 October), it is likely that these fish were a fall-run stock. All embryos were initially maintained at 8.0° C. After fertilization, groups of embryos were placed in constant temperature treatments of 4.0, 8.0, or 12.0° C. Control groups remained in their respective constant temperature treatments throughout the experiment. At some point during development, embryos from each group were transferred into one of the other two temperature treatments. For example, one group of eggs, initially placed in a bath of 4.0° C, would be later transferred to a bath of 8.0° C, while another group initially held at 12.0° C might be transferred to a treatment of 4.0° C. All test organisms were kept through the emergence stage.

The warmer the conditions that embryos were exposed to, the earlier they reached the emergence stage. This continues to corroborate earlier studies that reported similar observations, as well as results from Geist et al. (2006). For all Chinook embryos, survival was relatively good, always greater than 70%. Embryos that were transferred from warmer to cooler treatments tended to have higher overall survival through emergence (≥90%) than did all embryo groups started at the coldest treatment (between 70-90%). It was also noted that embryos that were initially exposed to the warmest treatment and then transferred to a cooler treatment were longer and heavier at emergence than were cohorts from other treatment exposures. These data tend to indicate that a natural thermal regime, falling through winter and then rising into spring, results in more robust fry than might constant thermal exposure throughout incubation.

Murray and McPhail (1988)

In this study, the thermal environment that embryos were exposed to was constant; it did not follow a normal, variable regime. This study actually focused on all five species of Pacific salmon: sockeye salmon, pink salmon, chum salmon, coho salmon, and Chinook salmon. The questions being investigated were how various constant thermal exposures affected survival through emergence, as well as timing of development, and size and weight of fry at emergence. The Chinook salmon used in this study originated from the Babine River, British Columbia. Embryos were fertilized at a temperature of 14.0° C. Embryos from each of the salmon species were maintained in the following constant temperature conditions: 2.0, 5.0, 8.0, 11.0, and 14.0° C. Water velocity through the incubation troughs was estimated to be 534 cm/H, and dissolved oxygen was kept at ≥85% saturation. Embryos of each species were maintained through the emergence stage.

For all species, it was reported that time to both hatch and emergence was inversely related to water temperature. Warmer test temperatures accelerated development and resulted in earlier hatch and emergence. For Chinook embryos, mortality from fertilization through emergence was very high at a constant incubation temperature of 2.0° C (86%), fairly low at constant temperatures of 5.0, 8.0 and 11.0° C (range of 10-17%), and moderate at a constant temperature of 14.0° C (54%). The data collected on the size and weight of individual Chinook fry at the time of emergence showed that fish incubated at a constant 5.0° C were longer and heavier than fish incubated at the other test temperatures (Figures 12 and 13). However, it should be noted that a constant incubation temperature of 5.0° C (or any temperature for that matter) does not occur in nature where Chinook salmon embryos incubate.

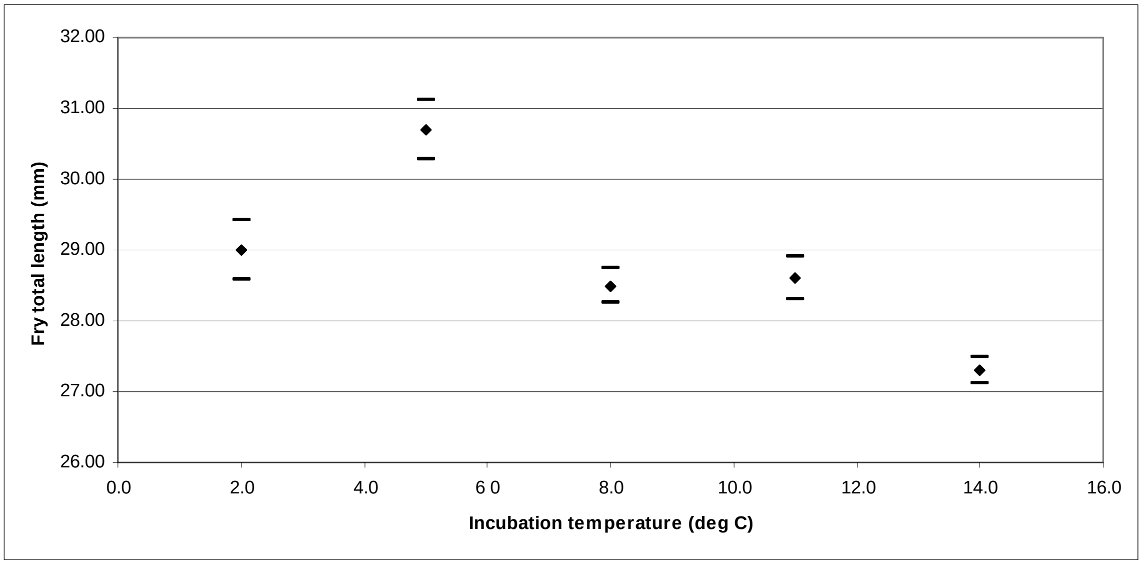

Figure 12. Mean length (and 95% confidence interval) for emergent Chinook salmon fry after incubation at various constant temperatures (data from Murray and McPhail 1988).

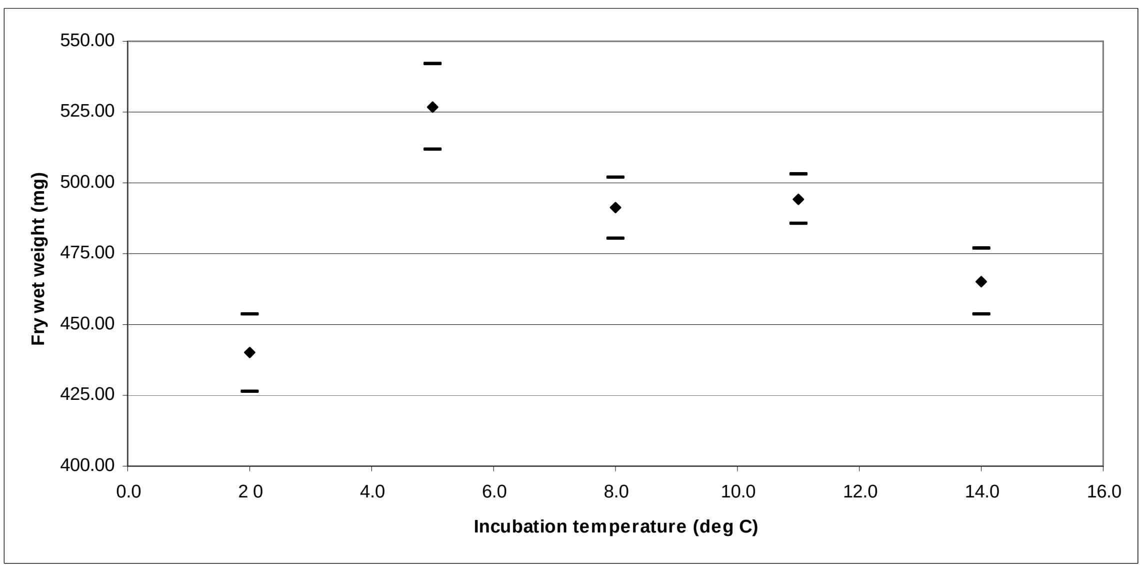

Figure 13. Mean weight (and 95% confidence interval) for emergent Chinook salmon fry after incubation at various constant temperatures (data from Murray and McPhail 1988).

The most informative results from this study concerns the differences observed among the five different Pacific salmon species. For example, at the highest treatment temperature (14.0° C) it was observed that chum and Chinook salmon had the lowest mortality, 50% and 54%, respectively, while the other three species had mortalities that ranged between 78 and 92%. Sockeye salmon were noted as being the species least able to tolerate warmer water temperature. The authors concluded, “Each species is adapted to different spawning times and temperatures, and thus indirectly adapted to specific incubation temperatures”. Subjecting developing embryos to constant thermal conditions throughout incubation does very little to help us to learn how specific, naturally variable thermal regimes may result in embryo survival; however, as the data from this study illustrate, these types of constant temperature tests can help us to discern different thermal tolerances among similar species.

Beacham and Murray (1989)

The tests conducted in this study were done to assess differences in incubation development and survival, based on water temperature, between both Chinook salmon and sockeye salmon, as well as between two distinct stocks of Chinook salmon. The Chinook stocks used in this study originated from the Fraser River system, British Columbia. The two distinct Chinook salmon stocks that were compared came from a coastal and an inland run, and while it was not specifically stated, it appeared that they were both a spring-run stock. The thermal conditions that adults may have been exposed to prior to spawning were not described. All embryos were exposed to one of five constant temperature treatments (2.0, 4.0, 8.0, 12.0, and 15.0° C). Test organisms were maintained through the emergence stage.

As with other studies, this one corroborated that warmer temperature during incubation resulted in accelerated embryo development, and that emergence occurred earlier for those embryos exposed to warmer conditions. This was true for both Chinook salmon and sockeye salmon. Again it was observed that Chinook salmon tended to have better survival at warmer temperatures, and that sockeye salmon appeared to be better adapted to cooler temperatures. Finally, there was little evidence that differences in thermal adaptation existed between the two Chinook stocks. However, the authors continually brought up in their discussion the supposition that local stocks are adapted to local thermal conditions.

Beacham and Murray (1990)

This paper is quite involved and provides some very good information concerning Pacific salmon incubation in relation to water temperature. However, it should be noted that all of the data used in the development of this work were based on constant temperature exposure of test organisms. The point that constant temperature conditions are not representative of what occurs in the natural environment cannot be stressed enough. As well, the authors acknowledge that the information provided was mainly for the accurate prediction of hatching and emergence timing, and was of practical interest for managers involved in salmon culture (hatchery environs). The basic design of this work was to subject embryos of all five common Pacific salmon species to various constant temperature regimes in order to determine the upper and lower temperature at which 50% mortality occurred, to determine if differences existed in the size and weight of fry exposed to different thermal treatments, and to develop and compare various models useful in estimating the timing to hatch and emergence.

The authors were able to determine that for Chinook fry, a constant temperature of 2.0° C resulted in 50% mortality through emergence; however, they were not able to determine (based on the data used) what upper temperature resulted in 50% mortality through emergence. As with other studies, it was reported that fry resulting from warmer, constant temperature exposures tended to be smaller and weigh less than cohorts that had been exposed to cooler temperatures. Finally, while there were slight differences in how the various developmental models described timing through hatch and emergence, all of them had very low sums of squares and r-square values ≥0.99. It was determined that none of the mathematical models were any better or worse at describing developmental timing.

In the end, the authors acknowledged that all of their results were based on data from constant temperature treatments, and did not reflect what would be expected to occur in the natural habitat. The authors also noted that the data provided insight as to the variation among Pacific salmon with respect to how water temperature affected embryonic development rate, survival, and fry size and weight. A very telling quote from the conclusions was, **"Because the species showed different trends in emergence timing with respect to changes in development temperature, it seems reasonable to infer that these different trends reflect adaptive variation in the species' response to environmental temperature during development"**. And finally, the authors noted, **"Population-specific differences in development can also exist, and populations that spawn in extreme environments can probably be expected to have different rates of development and survival than populations in more moderate environments"**. This paper establishes a very good base for understanding that not only are there species-specific differences in how Pacific salmon are differentially adapted to various thermal environments, but also how population-specific adaptations are likely.

Geist et al. (2006)

This paper centers on how elevated water temperature coupled with low dissolved oxygen during early incubation might affect development and survival of Chinook salmon embryos. The fish used for this work originated from the Snake River, and were a fall-run stock of Chinook salmon. Prior to obtaining gametes, adults were held at the Lyons Ferry Hatchery, and were exposed to a fairly constant temperature of 12.0° C. After gametes were fertilized, they were subjected to one of 14 different temperature-dissolved oxygen treatments. Six replicates were maintained within each treatment, and as such statistical analysis was able to be conducted on the results. Test organisms were maintained through the emergence stage. Survival data was collected at various stages of development, including eye-up, hatch, and emergence.

The various treatments included five initial temperatures of 13.0, 15.0, 16.0, 16.5, and 17.0° C, coupled with four initial dissolved oxygen levels of 4.0, 6.0, 8.0 mg/L or 100% saturation. Test organisms in the temperature groups of 13.0 and 17.0° C were only exposed to 100% saturation of dissolved oxygen. Each temperature group had a declining thermal regime equal to 0.2° C per day through the first 40 days of the tests. After day 40, all treatments were thereafter exposed to a normal Snake River temperature regime as described by the mean daily water temperature of the upper Hells Canyon Reach among the years 1991-2003. As well, initial dissolved oxygen levels were maintained through the first 16 days, whereupon they were then increased by 2.0 mg/L. On day 39 they were again increased by 2.0 mg/L, and after day 40 they were maintained at 100% saturation.

Among the several studies available to date, Geist et al. (2006) is one that tests results based on using replicates within each treatment (allowing for statistical analyses), as well as exposing embryos to several different naturally varying thermal-dissolved oxygen regimes. The authors reported that survival of developing embryos was linked only to temperature. The only group that was statistically different was the one initially exposed to 17.0° C; all other groups were similar and had mean survivals ≥83% (see Table 2 in Geist et al. 2006). These results comport well with other studies that subjected embryos to thermal regimes resembling what occur in natural systems.

The authors reported that development timing was accelerated at higher temperature, and at higher dissolved oxygen levels (see Table 3 in Geist et al. 2006). Again, this information comports well with what other, earlier researchers have reported.

Lower dissolved oxygen tended to result in an increase in abnormalities. Groups initially held at 4.0 mg/L dissolved oxygen generally had twice as many abnormalities as groups started at higher levels; however, this was still a very small proportion of any group (≤6.0%), and there was no statistical difference among groups.

Finally, the growth of embryos was only very slightly affected by differences in temperature and dissolved oxygen. The wet weight at hatch, as well as the wet weight and fork length at emergence were statistically similar among all groups. While the fork length of alevins at hatch differed among treatments, the largest difference was only 1.0 mm; it is difficult to infer that this difference would have a profound effect on later survival, especially since at emergence this difference no longer existed. The most important difference that was observed, with respect to growth, was that yolk conversion efficiency tended to be better in embryos initially exposed to higher dissolved oxygen levels. At emergence, the dry weight of fry was not different among treatment groups; however, the amount of yolk was significantly less in groups that were initially exposed to 100% saturation of dissolved oxygen.

The authors did note that adults used in their tests were not exposed to normal river temperatures prior to spawning. Adults were maintained in water having a constant temperature of 12.0° C, and the authors note that this might have an undetermined effect on the final results of their experiment. Unfortunately, they correctly noted that there are no studies that have, as yet, successfully maintained adult Chinook salmon at elevated water temperature prior to spawning.

One potential criticism of this study (and other incubation studies) is that flow rates past the developing embryos in the laboratory may not have been representative of what actually occurs in the natural hyporheic environment of a redd. The authors noted that during their experiment the flow rate through the advanced post-hatch stage was maintained at about 0.18 cm/s. There is only one other study involving Chinook salmon that reported on flow rate, and that was Heming (1982); in that study, the flow rate was maintained at 0.22 cm/s. Recent research with the use of artificial redds in the Snake River in Hells Canyon estimated inter-redd horizontal water velocities during the incubation period to range from a mean of 0.14 cm/s to 1.06 cm/s at the various artificial redd sites with an overall mean among all artificial redd sites of 0.55 cm/s (Hanrahan et al. 2007). During the latter portion of the incubation period, the horizontal velocity component through the artificial redds leveled to a median value of 0.21 cm/s. These finding suggest that the laboratory studies of Geist et al. (2006) closely represent velocity conditions observed in the natural environment.

4.6.2 Synthesis of incubation survival evaluations

In summary, based on the above literature review, several consistent findings emerge regarding temperature and incubation. First, and most important, experiments based on constant and naturally varying thermal regimes provide very different results with respect to both ultimate survival and size of fry at emergence. Certainly there is more information in the available literature that describes results from constant temperature experiments; however, they do not accurately reflect what is typical in a natural river environment. However, there are only a few studies that successfully mimicked natural thermal conditions to determine how water temperature during early incubation may ultimately affect the survival of Chinook salmon fry in a natural environment. These various studies, when synthesized, also indicate that the ultimate incubation survival of Chinook salmon embryos is not affected only by a specific temperature, but more importantly, survival is directly related to the length of time that embryos are exposed to elevated thermal conditions. With respect to fry size at emergence, most all data that indicates warmer temperature produces smaller fry is based on single observation studies that did not maintain replicates, and could not be statistically analyzed. While some researchers may still maintain that warmer incubation conditions generally produce smaller fry, it is also apparent that those fry emerge and begin feeding earlier than their cohorts exposed to cooler conditions. There is no evidence that earlier emerging fry are subjected to a reduced survival advantage. In fact it has been postulated that early emergence and feeding may provide a distinct territorial and growth/survival advantage.

To assess the thermal requirements for incubating fall Chinook salmon in a riverine environment, three of the studies reviewed provide the most complete information. Olson and Foster (1955), Olson et al. (1970), and Geist et al. (2006) provide objective mortality data for fall-run Chinook salmon based on temperature treatments that mimicked natural conditions. The data from these three studies were compiled, and a database developed that relates the ultimate fry mortality of each egg lot to the highest temperature they were exposed to during tests. A plot of the data reveals that mortality was relatively low through about 16.0° C, but between 16.0 and 17.0° C mortality sharply increased (Figure 14).

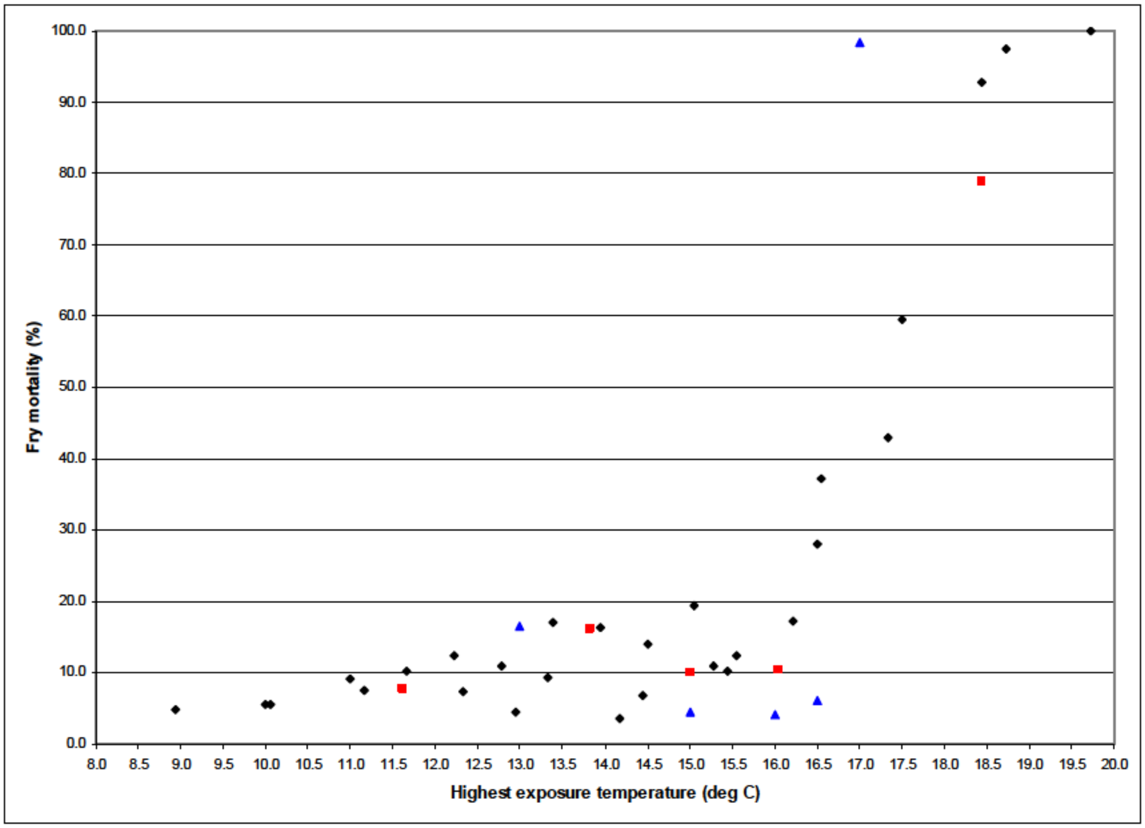

Figure 14. Final fry mortality (%) relative to the highest water temperature (ºC) that embryos were exposed to during natural/variable temperature experiments (data from Olson and Foster (1955), Olson et al. (1970), and Geist et al. (2006)).

The data was further placed into categories that would allow for statistical analysis. As an example, all mortality data that resulted from a highest exposure temperature between 12.6 and 13.5° C were placed in a group represented by 13.0° C. This was done for six temperature categories including 12.0, 13.0, 14.0, 15.0, 16.0, and 17.0° C. Two other groups were made, for 10.0 and 19.0° C, and included all mortality data that resulted from highest exposure temperatures less than 11.6 and greater than 17.5° C, respectively. After the data were assigned to specific groups, the mean mortality was calculated for each thermal category and plotted that data along with the estimated 95% upper and lower confidence interval (Figure 15).

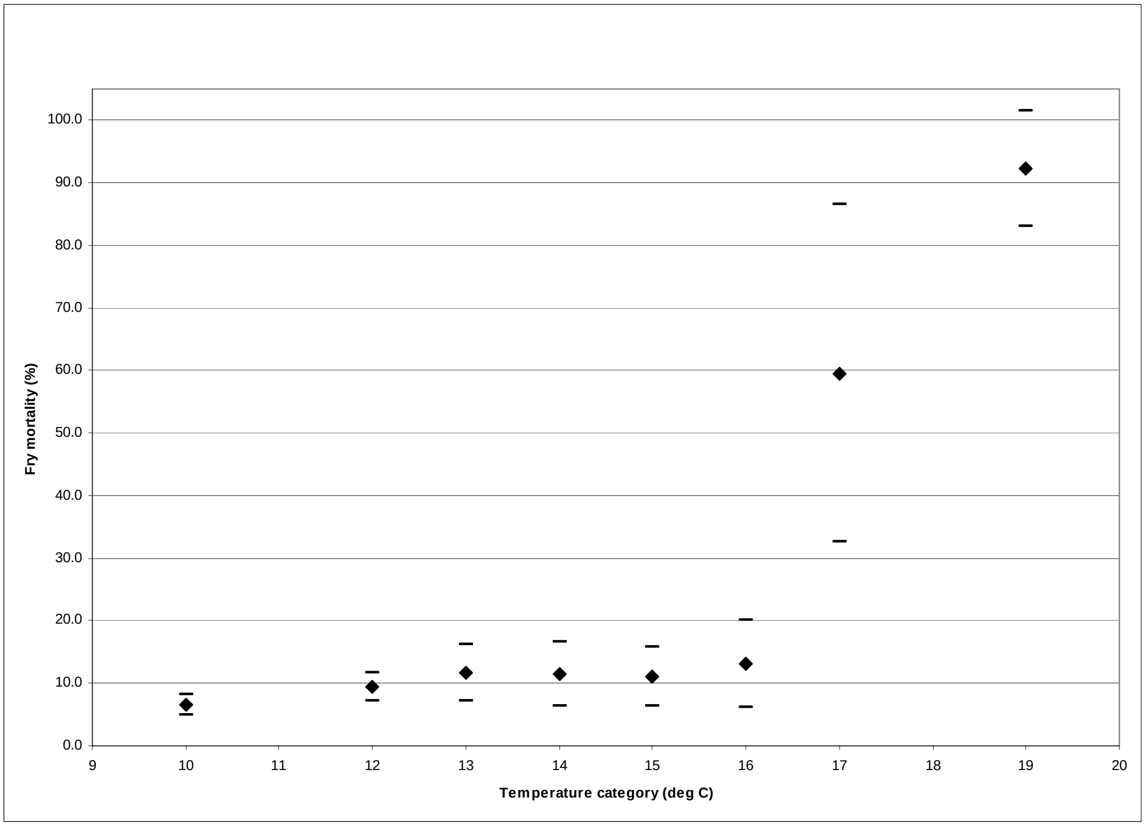

Figure 15. Mean fry mortality (with 95% confidence interval) within thermal exposure categories

It becomes apparent that the mean mortality data was low and similar across all thermal exposure categories, 10.0 through 16.0° C. However, the categories represented by 17.0 and 19.0° C had very high and more variable mortality. The data for each temperature exposure category was finally tested using a series of t-tests (α =0.05) against all other data in order to determine if a statistical difference existed among the various categories. The results are shown in Table 7, and confirm that mortality is statistically similar among all of the temperature exposure categories from 10.0 through 16.0° C, and that while the categories representative of mortality at 17.0 and 19.0° C are statistically similar to each other, those data indicate that mortality at those temperatures is significantly greater than at all lower temperatures.

Table 7. T-test matrix showing the P-value calculated from comparing the mean mortality values between each temperature exposure category. Significant values (P≤0.05) are in bold and are italicized; highly significant values (P≤0.01) are in bold, italicized, and underlined.

Temperature exposure categories (with sample size)								
	10.0 n=5	12.0 n=4	13.0 n=5	14.0 n=5	15.0 n=5	16.0 n=6	17.0 n=4	19.0 n=4
10.0		0.0901	0.0907	0.1354	0.1338	0.1254	***0.0307***	***<u><0.01</u>***
12.0	0.0901		0.4153	0.5120	0.5635	0.3622	***0.0353***	***<u><0.01</u>***
13.0	0.0907	0.4153		0.9355	0.8476	0.7506	***0.0383***	***<u><0.01</u>***
14.0	0.1354	0.5120	0.9355		0.9190	0.7105	***0.0373***	***<u><0.01</u>***
15.0	0.1338	0.5635	0.8476	0.9190		0.6426	***0.0369***	***<u><0.01</u>***
16.0	0.1254	0.3622	0.7506	0.7105	0.6426		***0.0392***	***<u><0.01</u>***
17.0	***0.0307***	***0.0353***	***0.0383***	***0.0373***	***0.0369***	***0.0392***		0.0929
19.0	***<u><0.01</u>***	***<u><0.01</u>***	***<u><0.01</u>***	***<u><0.01</u>***	***<u><0.01</u>***	***<u><0.01</u>***	0.0929	

The data from these three studies are very consistent and are likely the best information that can be used to describe how fall-run Chinook salmon embryo incubation mortality can be affected by temperatures characterized by a naturally varying thermal regime. They all used similar stocks of fall-run Chinook salmon, and conducted exposure tests in a similar, repeatable manner. They all had very similar results. The data were compiled and analyzed based on the highest temperature experienced by test organisms. This was done because as the data were being reviewed, it was obvious that even though tests were designed so that the initial exposure temperature would be the highest, this was not always the case. Because of natural variability experienced in the Olson et al. (1970) study, the highest temperature within each treatment occurred a few days after the experiment had begun. However, if the initial test temperatures were used, the results are the same. Constant temperature exposure tests are not representative of conditions found in a natural environment, and tend to indicate that when water temperature is higher than about 13.0° C, then extensive mortality would be expected to occur during incubation. However, by using data from naturally varying exposure tests, it appears more reasonable that when incubating embryos are subjected to an early elevated temperature as high as 16.0° C, and that their exposure is to a normal declining thermal regime, they should not be expected to experience abnormal/excessive levels of mortality. This information is more realistic than results and recommendations based on constant temperature exposure tests. This type of information also makes it evident that it should be possible to develop a realistic site-specific spawning/incubation temperature criteria for the Snake River fall Chinook salmon.

Based on these studies, it is the conclusion of IPC that the thermal shift created by Hells Canyon Complex has had very little adverse impact on the success of incubation survival for those redds spawned at initial temperatures of between 16 ºC to 16.5 ºC. These redds do not experience different levels of mortality from those eggs spawned at temperatures as low as 13 ºC. At temperatures above 16.5 ºC, mortality of incubating embryos substantially increases. In the upper Hells Canyon Reach, temperatures can be above 16.0 ºC on average between October 10 and October 18. This suggests that redds constructed during this time period may have lower survival than redds constructed after this time period. Redds constructed after this period have equal probability of survival regardless of the temperature at which they were constructed. This suggests that less than 2% of redds in an average spawning distribution would be affected by elevated temperatures (Chandler et al. 2001). Although the thermal shift that occurs below Hells Canyon Dam delays cooling of water temperature in the fall it significantly advances the emergence timing of juvenile fall Chinook salmon, closer to what occurred historically in the primary production areas upstream of the Hells Canyon Complex.

4.7 Effects of Intragravel Water Temperature

There has been concern expressed by some that water column metrics to evaluate the thermal effects on incubating fall Chinook salmon may not be representative of actual intergravel (inter-redd) temperature conditions. For example, past reports (e.g. Geist et al. 1999, Hanrahan et al. 2004) have indicated that water temperature within the intragravel environment (where Chinook salmon embryos incubate) is roughly 2-3°C warmer than conditions in the water column throughout the incubation period. A difference of this magnitude would be of significant concern, especially when evaluating site specific fall Chinook salmon spawning water quality criteria that is based on water column conditions, and does not take into account what might be present in the intragravel incubation environment. However, these reports should be put in proper context. Also, there is more recent data that can help researchers, managers, and regulators to better understand this thermal difference between the two environments.

Early data collected by Geist et al. (1999) and Hanrahan et al. (2004) came from measurements obtained from piezometers installed into the ambient shallow and deep hyporheic environment (as deep as 150 cm) into the undisturbed gravel substrate. While these data were collected in gravel areas where Chinook salmon would normally be expected to spawn, the data presented in those reports do not represent thermal conditions present in Chinook salmon redds.

The thermal environment within Chinook salmon redds can be strongly influenced by surface water conditions (Geist et al. *In press*). Modification of the substrate composition during redd construction alters the local hydraulics and permeability of the shallow hyporheic zone, and allows for a high degree of exchange between the surface water and the inter-redd environment (Burner 1951; Vronskiy 1972; Chapman 1988; Hanrahan 2007). Chinook salmon also tend to spawn where the natural down-welling of surface water into the shallow hyporheic zone occurs (Vronskiy 1972; Leman 1988; Vronskiy and Leman 1991; Geist 2000; Geist et al. 2002; Hanrahan et al. 2004). The use of predominantly down-welling spawning habitats by Chinook salmon contrasts with other Pacific salmon species, such as chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*), which tend to spawn in areas that have strong up-welling conditions, and can experience larger thermal gradients between surface water and the shallow hyporheic zone (Tautz and Groot 1975; Leman 1988; Geist et al. 2002). Redistribution of the substrate and reduction of fine material during redd construction, and the disposition to spawn in a naturally down-welling environment, facilitate increased interaction between surface water and the incubation environment within Chinook salmon redds. This can result in physicochemical similarities between surface waters and the inter-redd environment, specifically with relation to temperature. This similarity makes it feasible to use surface water temperature data as a reliable surrogate for describing the thermal environment that Chinook salmon embryos experience during incubation.

The thermal environment within a Chinook salmon redd in a large river can be more variable than surface water conditions, especially as the incubation season progresses following redd construction and deposition of eggs. However, in the Snake River, temperature within the redd environment is generally the same as what is present in the water column, especially during the first few weeks following redd construction. Similar findings have been reported by Ringler and Hall (1975), Vronskiy and Leman (1991), Hanrahan et al. (2004), and Hanrahan (2007), which were based on data collected from artificial redds. The following eight graphs depict the mean water column and inter-redd temperatures (for redds constructed in early November 2004 and 2005) measured at sites studied in the upper Hells Canyon of the Snake River (Figures 16 through 23 . Note that if it is difficult to discern the lines differentiating the water column and the inter-redd environment, that is because they fall directly on top of each other.

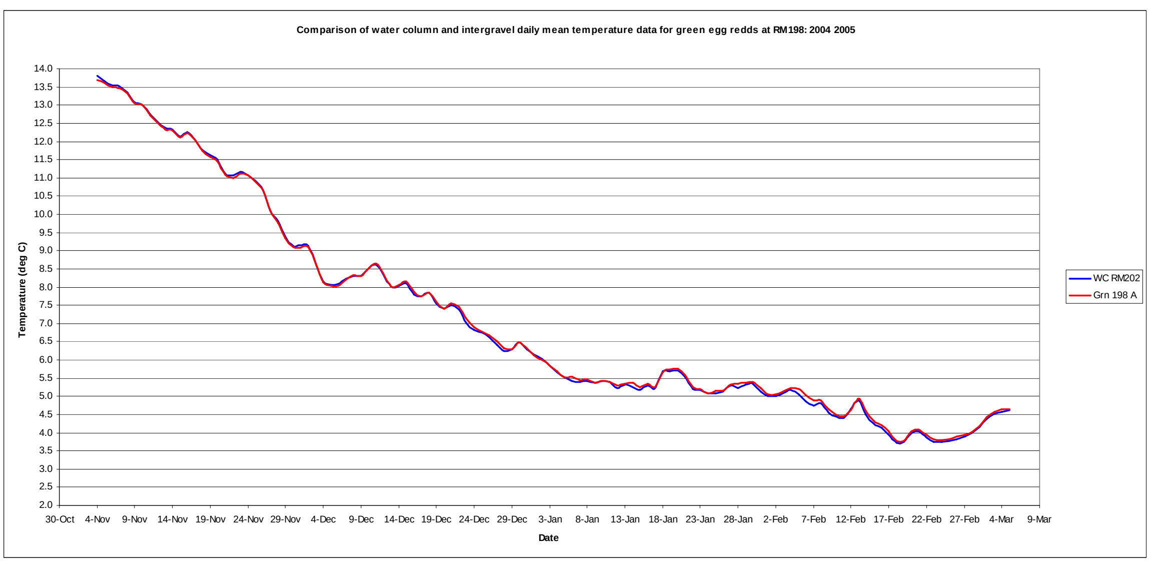

Figure 16. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 198 during the years 2004-2005.

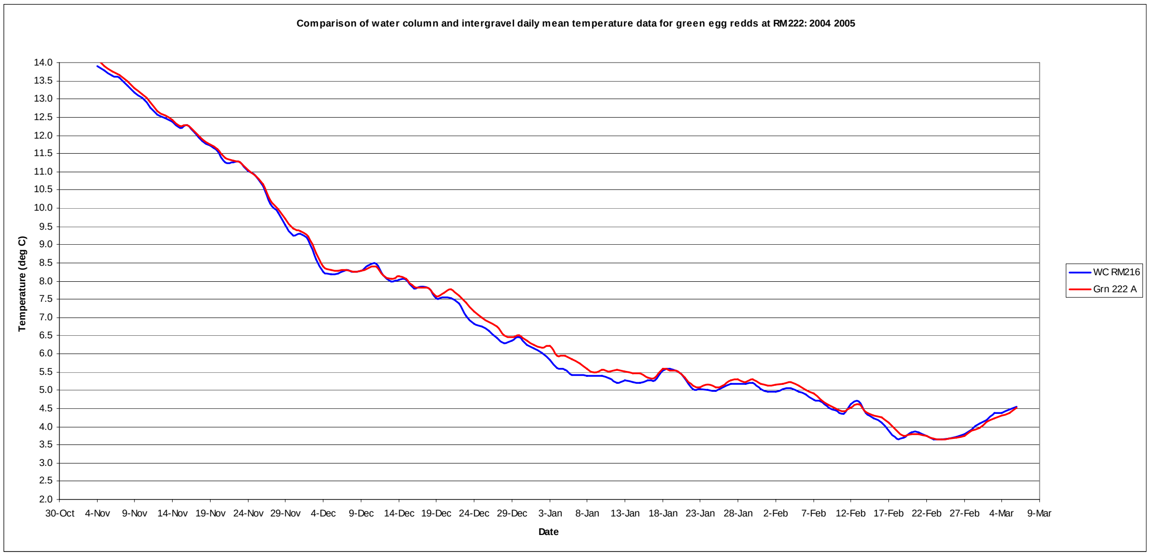

Figure 17. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 222 during the years 2004-2005.

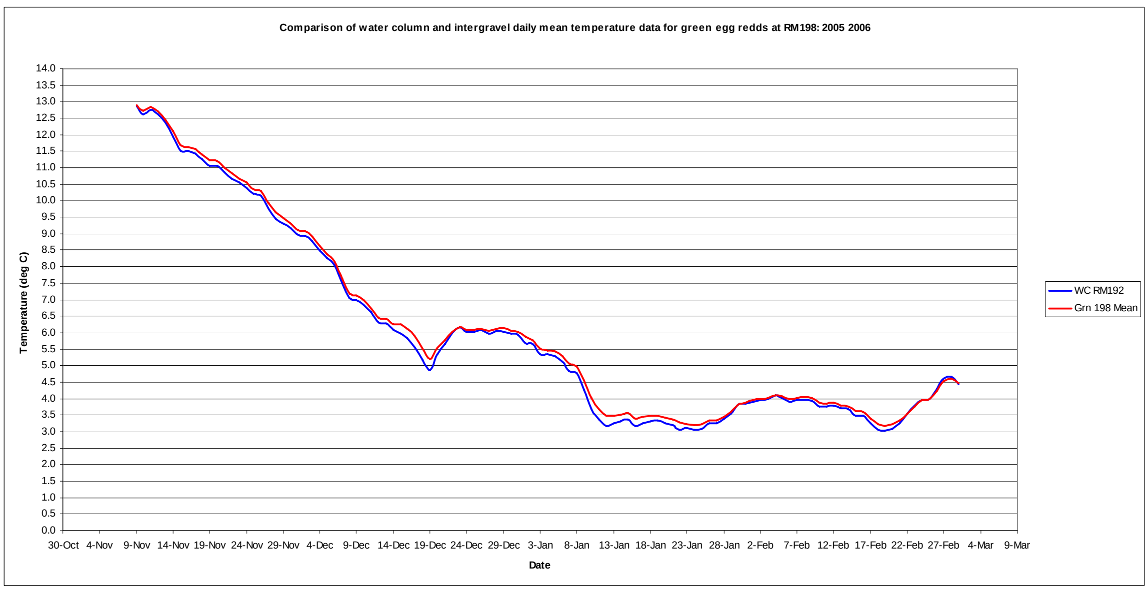

Figure 18. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 198 during the years 2005-2006.

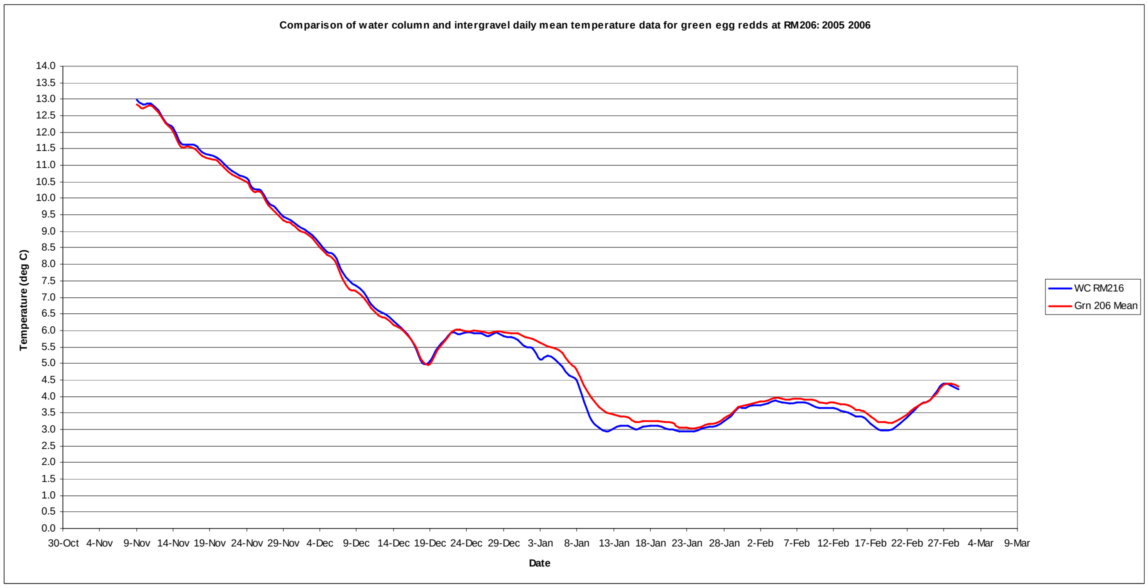

Figure 19. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 206 during the years 2005-2006.

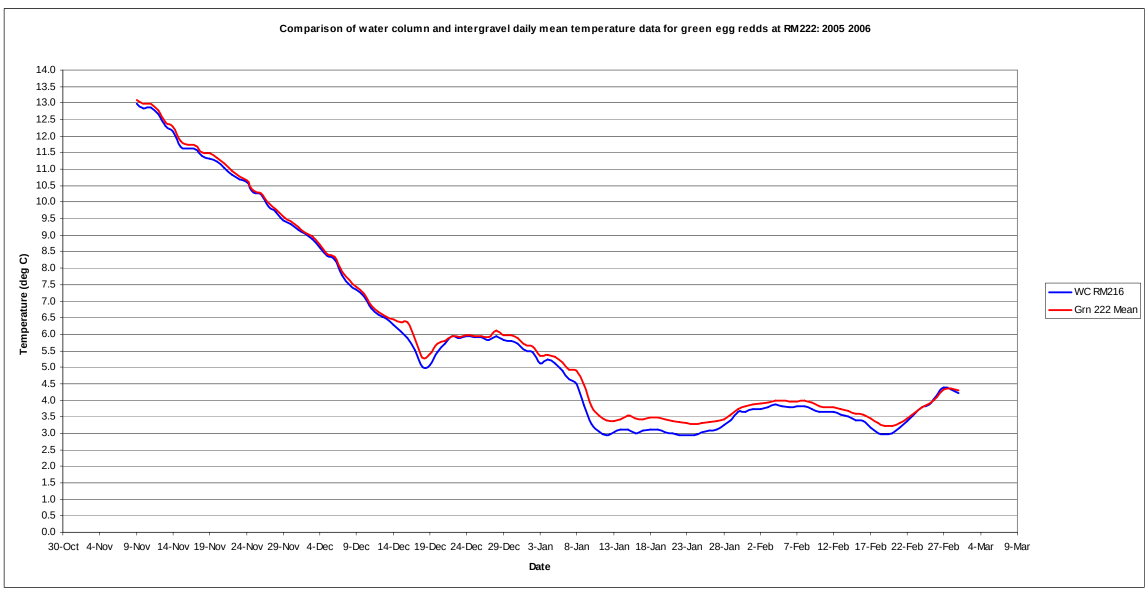

Figure 20. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 222 during the years 2005-2006.

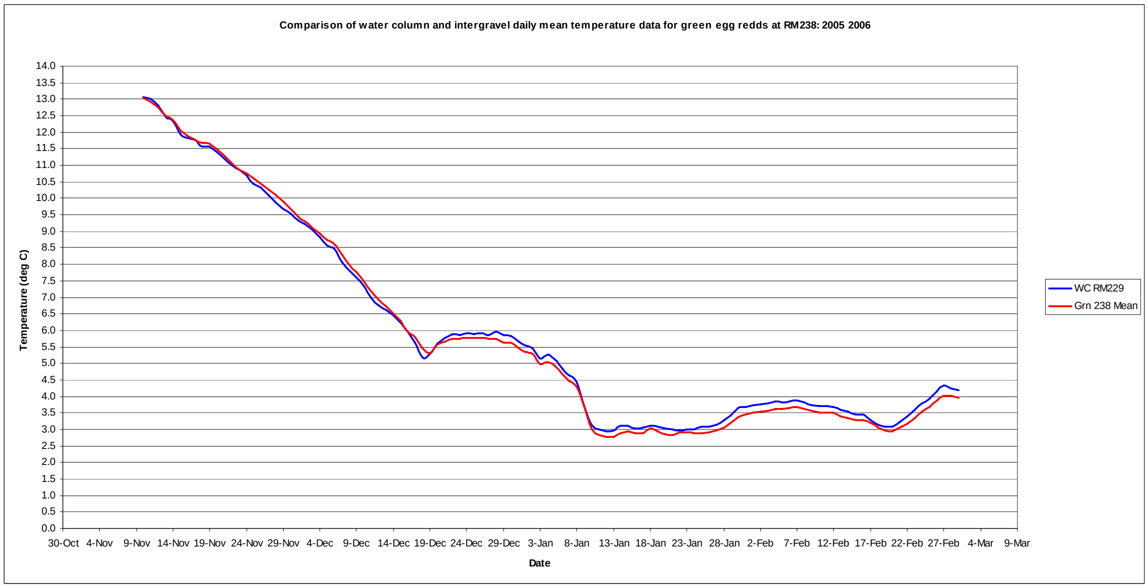

Figure 21. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 238 during the years 2005-2006.

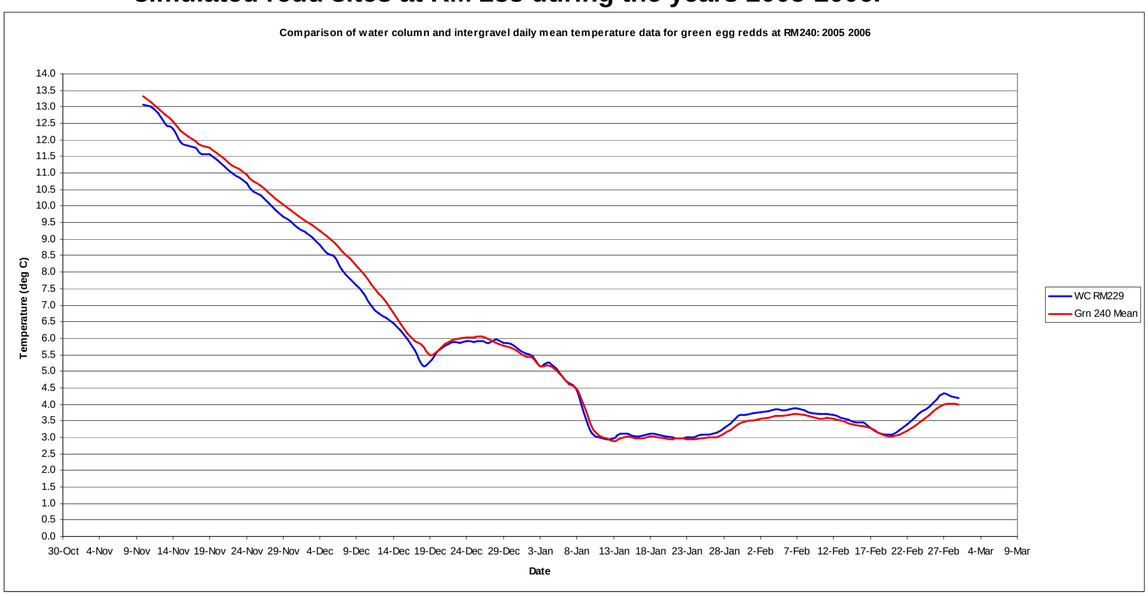

Figure 22. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 240 during the years 2005-2006.

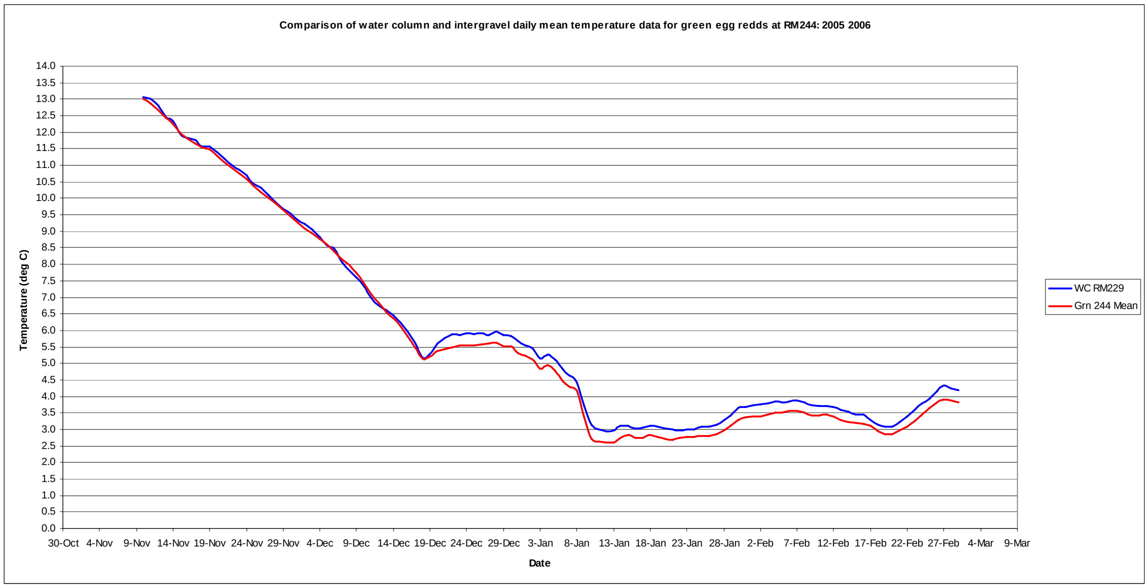

Figure 23. Comparison of water column and inter-redd environment water temperatures at simulated redd sites at RM 244 during the years 2005-2006.

These data clearly show that for approximately five weeks post construction the water temperature within a redd remains virtually identical to what is present within the water column. Furthermore, for individual artificial redds constructed in the upper Hells Canyon Reach during 2004 and 2005, the maximum temperature difference between the inter-redd environment and the water column, during the first five weeks following construction, was only 0.5°C, and averaged 0.1°C. As well, <u>***throughout the entire incubation period***</u>, the water temperature within individual redds tended to remain within approximately 0.5°C of what was measured in the water column.

4.8 Low Dissolved Oxygen and Water Temperature

The influence that water temperature may have on various life stages could be influenced by low levels of dissolved oxygen in the water adding a potential stressor. Often, laboratory studies relative to optimal temperature determinations are conducted under optimal dissolved oxygen levels, thus their application to the environmental condition being experienced by the particular life stage of fish may be limited. By late-August dissolved oxygen levels below Hells Canyon Dam are at their lowest, generally around 4.5 mg/L. Dissolved oxygen tends to remain at this low level through about the beginning of October, when it begins to increase rapidly, reaching levels generally ≥6.0 mg/L during the last week of October. While these levels are low, it should be understood that as water progresses downstream through the upper Hells Canyon Reach, it flows through a series of high gradient, turbulent rapids, which effectively increase the dissolved oxygen levels by about 2.0 mg/L by the time it reaches RM 238 (nine miles downstream of the Hells Canyon Dam), just downstream of Granite Rapids. In effect, any potential negative effects that may occur due to an interaction of increased water temperature and low dissolved oxygen would likely be restricted to that uppermost nine miles of the upper Hells Canyon Reach, during the earliest portion of the spawning period.

With respect to migrating adults, it is conceivable that fall Chinook salmon might be blocked from entering the most upstream nine miles of the Snake River spawning habitat during late-August through late-September when dissolved oxygen levels are at their lowest, and water temperatures can be between 19-22°C. However, after early to mid-October, dissolved oxygen levels are increasing above 4.5 mg/L, while water temperatures are quickly declining below 19.0°C. This would reduce the potential for a migration block into that upper nine miles of river by mid- to late-October, and would also reduce the potential for negative effects to occur to fertilized embryos.

It is also important to understand that during the past 16 years of spawning surveys below Hells Canyon Dam, only a very limited number of redds have been observed being constructed in the uppermost nine miles of the upper Hells Canyon Reach prior to the third week of October. Only during three of those years were redds observed prior to 21 October, and they amounted to 0.3% of the total spawning observed in the mainstem Snake River in those years.

Geist et al. (2006) evaluated the effects of low dissolved oxygen levels under different thermal conditions. Their various treatments included five initial temperatures of 13.0, 15.0, 16.0, 16.5, and 17.0° C, coupled with four initial dissolved oxygen levels of 4.0, 6.0, 8.0 mg/L or 100% saturation. Test organisms in the temperature groups of 13.0 and 17.0° C were only exposed to 100% saturation of dissolved oxygen. Each temperature group had a declining thermal regime equal to 0.2° C per day through the first 40 days of the tests. After day 40, all treatments were thereafter exposed to a normal Snake River temperature regime as described by the mean daily water temperature of the upper Hells Canyon Reach among the years 1991-2003. As well, initial dissolved oxygen levels were maintained through the first 16 days, whereupon they were then increased by 2.0 mg/L. On day 39 they were again increased by 2.0 mg/L, and after day 40 they were maintained at 100% saturation. The authors reported that survival of developing embryos was linked only to temperature. The authors reported that development timing was accelerated at higher temperature, and at higher dissolved oxygen levels (see Table 3 in Geist et al. 2006). Again, this information comports well with what other, earlier researchers have reported. Lower dissolved oxygen tended to result in an increase in abnormalities. Groups initially held at 4.0 mg/L dissolved oxygen generally had twice as many abnormalities as groups started at higher levels; however, this was still a very small proportion of any group (≤6.0%), and there was no statistical difference among groups. Finally, the growth of embryos was only very slightly affected by differences in temperature and dissolved oxygen. The wet weight at hatch, as well as the wet weight and fork length at emergence were statistically similar among all groups. While the fork length of alevins at hatch differed among treatments, the largest difference was only 1.0 mm; it is difficult to infer that this difference would have a profound effect on later survival, especially since at emergence this difference no longer existed. The most important difference that was observed, with respect to growth, was that yolk conversion efficiency tended to be better in embryos initially exposed to higher dissolved oxygen levels. At emergence, the dry weight of fry was not different among treatment groups; however, the amount of yolk was significantly less in groups that were initially exposed to 100% saturation of dissolved oxygen.

4.9 Growth of Juvenile Fall Chinook Salmon

Thus far, the analysis of temperature has focused primarily on effects of survival or fitness of fall Chinook salmon. Another aspect of temperature is how it may affect growth, which may have both direct and indirect effects on survival. In earlier sections, growth and development of incubating embryos relative to temperature was discussed. For returning adults, growth relative to water temperature is not a relevant issue because adult fall Chinook salmon are not feeding or experiencing somatic growth. Growth in adult fall Chinook salmon is relevant primarily to the development and viability of gametes, which was discussed in earlier sections. This leaves the consideration of growth of rearing juvenile fall Chinook salmon relative to temperature and the effects of the thermal shift below Hells Canyon Dam. Juvenile Chinook salmon, including fall Chinook, that rear in the Snake River exhibit exceptional growth. Juvenile fall Chinook below Hells Canyon Dam exhibit rapid growth by comparison with those of other ocean type fall Chinook salmon populations and are equal to, or better than, growth rates reported for productive brackish and saltwater habitats along the Pacific coast of North America.

Connor and Burge (2003) note that fry of Snake River fall Chinook salmon rearing downstream of the Hells Canyon Dam (in different river reaches) grow at different rates. Based on recapture of PIT-tagged fry within each reach, they estimated that fry in the upper contemporary reach grow at approximately 1.2 mm/day, and fry in the lower reach grow at approximately 1.0 mm/day. Based on the way they calculated these growth rates, they then speculated that fry in the historic Marsing Reach may have grown at a slightly greater rate, 1.4 mm/day.

IPC evaluated potential growth rates using a different approach than that of Connor and Burge (2003). Rather than establishing an index period to calculate mean water temperature of each reach (March 20 through June 20), IPC, using the same data-set with the inclusion of four additional years, developed a growth model as a function of local water temperature (Figure 24). This data set includes PIT-tagged fish from both the upper and lower reaches of the Snake River downstream of the Hells Canyon Dam. IPC calculated increments of growth in fork length of PIT-tagged fish that were captured and recaptured in local areas over short periods (less than 10 days). IPC used thermal data from each reach, over the same capture-recapture periods, to define a thermal exposure condition (in one degree Celsius increments) that was relevant to the growth period. In agreement with other researchers, this model indicates that growth of rearing fall Chinook salmon fry tended to increase from 10°C through about 17°C, and thereafter declines (Banks et al. 1971; Marine 1997; Connor et al. 2002; Connor and Burge 2003 Connor et al. 2003). Historically, for the Marsing and the upper Hells Canyon reaches prior to the construction of the HCC, water temperature began to exceed 17.0°C by about the end of May. Water temperatures in the mainstem Snake River presently exceed 17.0°C upstream and downstream of the Salmon River confluence by about 18 and 26 June, respectively, thus extending suitable growth conditions longer than what occurred historically. As discussed in the next section, juvenile sub-yearling originating from the mainstem Snake River downstream of Hells Canyon Dam tend to be more than 95% evacuated from their natal rearing areas by early June .

Based on this review, it is the conclusion of IPC that the thermal shift below the Hells Canyon Complex has not had an adverse effect on growth of juvenile fall Chinook salmon, and has extended suitable growing conditions.

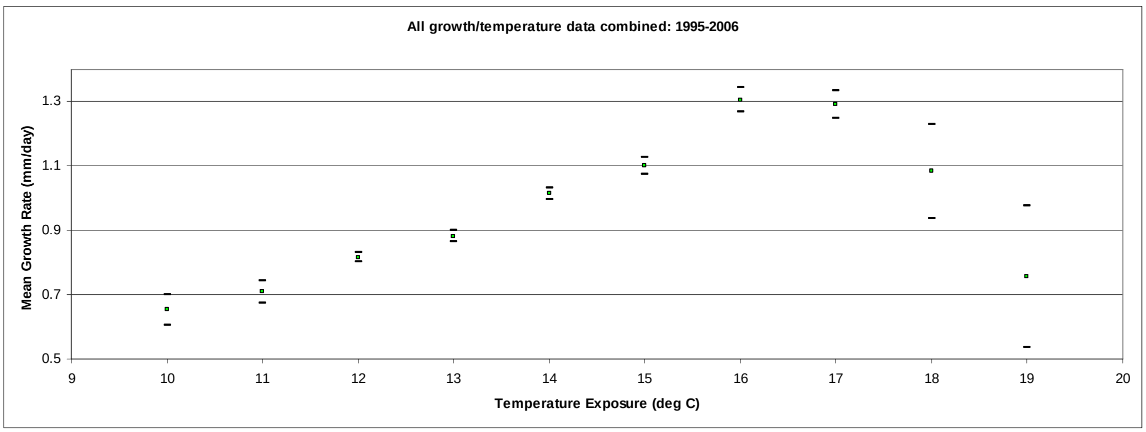

Figure 24. Mean growth rate of fall Chinook salmon fry rearing within the Snake River downstream of the Hells Canyon Dam, as a function of exposure to local water temperature conditions. The bars above and below each data point are the 95% confidence interval associated with each exposure temperature. Data was compiled from pit-tagged captures and recaptures within local rearing areas of the Snake River over periods of 10 days or less, for the spring seasons 1995 through 2003 (raw PIT tag capture and recapture data collected by the USFWS and made available through DART website).

4.10 Outmigration Timing

The potential effect of growth and development timing of juvenile fall Chinook salmon as a result of the temperature shift below Hells Canyon Dam may strongly influence the timing of the outmigration of juvenile fall Chinook salmon. This is a concern because it has been demonstrated that later migrating fall Chinook salmon juveniles experience lower survival to Lower Granite Dam than do earlier migrants (Connor et al. 2002). The thermal shift observed below Hells Canyon Dam is often identified as a causal factor in delayed migration timing as to when fall Chinook salmon migrate past Lower Granite Dam. The comparison of historic passage timing of sub-yearling Chinook salmon emigrants past the Central Ferry location on the Snake River (roughly 25 miles downstream of the present-day Lower Granite Dam), and the later contemporary passage timing of similarly aged fall Chinook salmon juveniles at Lower Granite Dam is often used as “evidence” of a shift in emergence timing, which is claimed to cause delayed rearing and emigration. In the recent past, up to 50% of the subyearling smolts from the upper reach of the Snake River passed Lower Granite Dam by early July, whereas historically it was believed that they were completely out of this reach by the end of June. This apparent delay in emigration is often attributed to later emergence timing than to what is believed to have occurred historically when production was in the Swan Falls Reach.

A more meaningful comparison relative to the effect of the HCC on emergence and emigration timing is to compare pre-Hells Canyon Complex temperatures of Hells Canyon to present day temperature of Hells Canyon. This comparison indicates that the Hells Canyon Complex warmed the incubation environment such that emergence timing today in Hells Canyon is much earlier relative to what it was pre-HCC. Further, post-HCC temperatures are much closer present-day to the historic Swan Falls spawning area. This suggests that construction of the HCC made the thermal regime of the Hells Canyon area more conducive to spawning incubation and early survival present-day than it was pre-HCC. In fact, Connor et al. (2002, 2005) support the proposition that the upper Hells Canyon Reach, the reach most closely influenced by the HCC, fosters an “ocean type” life history, whereas other reaches such as the Clearwater have significant delays in emergence relative to what occurred historically in the Swan Falls reach.

It is also interesting to note that migration timing of fish arriving at Lower Granite Reservoir is shifting earlier in more recent years. However, this shift to earlier emigration cannot be tied to the HCC, as the thermal regime and emergence timing has not shifted recently. This suggests that other factors beyond emergence timing strongly influence the timing of migration at Lower Granite Dam.

The following table (Table 8) is based on available passage data at Lower Granite Dam of juvenile pit-tag fall Chinook salmon originating from the mainstem Snake River (above and below the confluence with the Salmon River), as well as the overall Smolt Passage Index (SPI). The SPI includes naturally produced juveniles from the mainstem Snake River as well as the Clearwater, Grande Ronde, Salmon, and Imnaha rivers, in addition to all hatchery fish released at several locations throughout the Snake and Clearwater rivers. These data are publicly available through both the DART and PITAGIS web pages.

Table 8. Date of 50% and 90% passage at Lower Granite Dam for Age-0 wild fall Chinook salmon and also the date of Smolt Passage Index (SPI) for those percentages for the years 1995 and 2006.

Year	Date of 50% FaCH 0 Passage			Date of 90% FaCH 0 Passage		
	SPI	Wild FaCH Above	Wild FaCH Below	SPI	Wild FaCH Above	Wild FaCH Below
1995	30 Jul	20 Jul	30 Jul	20 Sep	18 Aug	04 Sep
1996	19 Jul	04 Jul	18 Jul	25 Aug	18 Jul	11 Aug
1997	15 Jul	11 Jul	13 Jul	16 Sep	05 Aug	08 Aug
1998	13 Jul	07 Jul	11 Jul	22 Aug	17 Jul	30 Jul
1999	03 Jul	04 Jul	25 Jul	15 Aug	31 Jul	15 Aug
2000	02 Jul	27 Jun	02 Jul	15 Aug	04 Jul	08 Aug
2001	03 Jul	No Data	06 Jul	07 Aug	No Data	03 Aug
2002	08 Jul	01 Jul	06 Jul	31 Jul	19 Jul	22 Jul
2003	18 Jun	25 Jun	29 Jun	12 Jul	10 Jul	12 Jul
2004	21 Jun	23 Jun	24 Jun	13 Jul	03 Jul	06 Jul
2005	03 Jun	11 Jun	15 Jun	19 Jun	23 Jun	29 Jun
2006	05 Jun	13 Jun	26 Jun	02 Jul	28 Jun	04 Jul

For data covering 1995-2006, the mean dates of 50% and 90% passage of wild fall Chinook salmon juveniles originating in the Snake River upstream of the Salmon River confluence at Lower Granite Dam are 30 June and 16 July, respectively. Note that the dates of 50% and 90% passage at Lower Granite Dam are becoming earlier.

Juvenile fall Chinook salmon growth tends to become reduced at temperatures >17.0°C. Water temperatures in the mainstem Snake River presently exceed 17.0°C upstream and downstream of the Salmon River confluence by about 18 and 26 June, respectively. Historically, these river reaches likely exceeded 17.0°C by about the end of May. This is approximately a two to three week difference, and the extended period of cooler conditions presently available in the river during the rearing period likely allows juvenile fish a longer opportunity for rearing.

One factor often overlooked in this assessment is that juvenile sub-yearling emigrants originating from the mainstem Snake River downstream of the Hells Canyon Dam tend to be more than 95% evacuated from their natal rearing areas by early June, and should be past Lower Granite Dam by the end of June, as was observed historically. This would be similar to the passage timing observed by Mains and Smith (1964). However, juvenile fall Chinook salmon originating from both the upper and lower free-flowing reaches of the Snake River must now navigate slack-water reservoirs downstream of their contemporary rearing grounds which results in delayed emigration through the lower Snake River (downstream of Lewiston, Idaho).

Fall Chinook salmon emerge earlier today in Hells Canyon than they did historically in Hells Canyon because of the warmer incubation conditions present today as a result of the HCC. Historically, Hells Canyon was a very cold environment and may not have been conducive for production of an Age-0 migrating fall Chinook salmon. The construction of the HCC altered the thermal regime such that emergence timing is now closer to what occurred historically in the production areas upstream of the HCC. During the 1990's, there was evidence that juvenile outmigration was delayed based on their arrival timing at Lower Granite Dam. Migration through the large slack water environment of Lower Granite Reservoir is more likely to explain the delay observed during that time. Recently, there is evidence of an earlier shift in the outmigration timing at Lower Granite. Fall Chinook salmon appear to be migrating earlier and at a smaller size than observed in the 1990's. Why this trend is occurring is uncertain, but may relate in some way to density in the rearing areas as adult returns and natural production has continued to increase.

5. A Summary of Conclusions

1. Significant anthropogenic influences on water temperature have occurred in the Snake River basin both upstream of Hells Canyon Dam and as a result of the Hells Canyon Complex. Generally, upstream of the Hells Canyon Complex is warmer during the spring and summer months relative to the pre-development era (pre-1860). This thermal inertia influences the magnitude and duration of the thermal shift downstream of Hells Canyon Dam that was created by the operation of the HCC.

2. The presence of the HCC has also created warmer over-winter base temperatures in the area below Hells Canyon Dam relative to the pre-development era because of the large volume of 4ºC water stored in Brownlee Reservoir over the winter months.

3. The primary effect of this altered thermal regime to the various life stages are as follows:

> *a. Adult migration* – There has been no apparent shift in adult migration timing. Adult fall Chinook salmon experience a similar period of exposure to temperatures elevated above 20 ºC between mid-August and mid-September as they did pre-HCC, but experience a lower maximum temperature than occurred historically. This is based on a comparison of current data with water temperatures present at Central Ferry in the early to mid-1950's, prior to construction of the HCC or the lower Snake River reservoirs.
>
> *b. Pre-spawn mortality* – Some level of pre-spawning mortality among anadromous salmonids is common. There is evidence that adult salmon in hatchery holding environments exposed to prolonged periods of water temperatures > 19 ºC could be subject to significant pre-spawn mortality. In hatchery holding situations, the mortality is usually associated with increased susceptibility to disease. However, fish-to-redd ratios documented in the Snake

River do not suggest excessive pre-spawn mortality of fall Chinook salmon. It may be that the non-confined environment of a large river under a naturally declining thermal regime and the potential of seeking cooler refuge makes fish less susceptible to disease and mortality. In addition, HCC operations cools late summer outflows relative to temperature levels associated with inflow and the operations of Dworshak Reservoir substantially cool areas associated with Lower Granite Reservoir and create thermal refugia during the early pre-spawn environment such that conditions prevalent today are better than conditions prior to the HCC.

c. Gamete viability – A through review of the literature demonstrates that studies often cited to suggest reduced gamete viability as a result of prolonged exposure to warmer temperatures should not be cited as supporting literature. The studies typically were not designed to address the question. One study that could be cited as supporting evidence (Jensen et al. 2006) did not hold adult Chinook salmon in a declining thermal regime typical of a riverine environment, but rather exemplified relatively long-term (40-days) exposure to elevated water temperatures. In addition, the control group held fish in a constant thermal environment of between 8 and 9 ºC, which cannot be compared to a declining thermal regime under more normative environments. Based on the available information for this topic, it is difficult to conclude that the HCC has had an adverse effect on development of gametes in returning adult fall Chinook salmon.

d. Disease susceptibility – Similar to the findings discussed under Pre-spawn mortality, adults held in confined hatchery environments under prolonged periods of elevated temperature appear to have a greater susceptibility to disease or fungal infections. How this pertains to free-ranging adults is uncertain. However as discussed above, fish to redd ratios do not suggest a high level of pre-spawn mortality below Hells Canyon Dam.

e. Spawn timing – There is no evidence that spawn timing has been greatly altered in the Snake River when comparing pre-HCC spawn distribution to that of the present-day Hells Canyon spawn distribution.

f. Incubation Survival – Experiments based on constant and declining thermal regimes differ markedly in their results with respect to both ultimate survival and size of fry at emergence. To assess the thermal requirements of incubating eggs in a natural declining thermal regime, Olson and Foster (1955), Olson et al. (1970) and Geist et al. (2006) are the most applicable findings to conditions experienced by Snake River fall Chinook salmon. These studies suggest that eggs spawned at initial temperatures of between 16 ºC to16.5 ºC do not experience different levels of mortality from those eggs spawned at temperatures as low as 13 ºC. At temperatures above 16.5 ºC, mortality of incubating embryos substantially increases. The thermal shift that occurs below Hells Canyon Dam delays cooling of water temperature in the fall and significantly advances the emergence timing of juvenile fall Chinook salmon closer to what occurred historically in the primary production areas upstream of the HCC. The Hells Canyon Reach is now more suitable for the expression of an Age-0 fall Chinook salmon life history than it was before construction of the HCC. The elevated winter base winter temperatures also contribute to the advanced emergence timing relative to pre-HCC.

g. Effects of intragravel water temperature – In Hells Canyon, there is a strong connection between the water column and the redd environment that allows for similar thermal conditions between the two environments. Therefore, the water column conditions provide good metrics for describing the thermal conditions of incubating embryos in Hells Canyon.

h. Emergence / Outmigration Timing - Fall Chinook salmon emerge earlier today in Hells Canyon than they did historically in Hells Canyon because of the warmer incubation conditions present today as a result of the HCC. Historically, Hells Canyon was a very cold environment and may not have been conducive to production of an Age-0 migrating fall Chinook salmon. The construction of the HCC altered the thermal regime such that emergence timing is now closer to what occurred historically in the production areas upstream of the HCC. During the 1990's, there was evidence that juvenile outmigration was delayed based on their arrival timing at Lower Granite Dam. Migration through the large slack water environment of Lower Granite Reservoir is more likely to explain the delay observed during that time. Recently, there is evidence of an earlier shift in the outmigration timing at Lower Granite. Fall Chinook salmon appear to be migrating earlier and at a smaller size than observed in the 1990's. Why this trend is occurring is uncertain, but may relate in some way to density in the rearing areas as adult returns and natural production has continued to increase.

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August 30th, 2007

Ms. Magalie Salas
Secretary
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, D.C. 20426

Re: Review of: Groves, P.A., J.A. Chandler, and R. Myers. 2007. White paper: The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon; by Dale A. McCullough.

Dear Secretary Salas:

Please accept the attached peer review of the above referenced White Paper submitted by Idaho Power Company in July 2007. Please contact me at 208-843-7355 if there are any problems with the transmission of this filing.

Sincerely,

Ryan Sudbury
Staff Attorney

Review of: **Groves, P.A., J.A. Chandler, and R. Myers. 2007. White paper: The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon. Final Report. Hells Canyon Complex, FERC No. 1971. July 2007.**

Dale A. McCullough
Columbia River Inter-Tribal Fish Commission
August 27, 2007

The recent review of the water temperature effects of Hells Canyon Complex on the Snake River fall Chinook by Groves, Chandler and Myers (2007) is evaluated here in each of its eight major parts. The work put into this IPC review was substantial and was thoughtfully done. Also, much new information was brought forward to this complex discussion that is useful in getting a fuller appreciation of the issues. Despite the depth of the response to each of the eight topic areas, it is my view that the IPC review does not present evidence on any of the topics that can argue successfully that providing warmer temperatures in the spawning season, allowing the thermal shift to persist, or that not addressing the summertime thermal problems below HCD is not a detriment to the Snake River fall Chinook. This is especially true given the substantial temperature increases that have already occurred in the Snake River in the last 50 years and the expected water temperature increases in the Snake River mainstem due to global climate change.

Also included is a brief discussion of Ehist. This was a computer temperature modeling effort conducted by IPC. In summary, much of the new information presented by IPC actually serves to further support the contention that IPC can make significant beneficial improvements to Snake River fall Chinook survival and production below HCD by effectively controlling water temperatures.

Adult Migration

3. The primary effect of this altered thermal regime to the various life stages are as follows:

a. *Adult migration* – There has been no apparent shift in adult migration timing. Adult fall Chinook salmon experience a similar period of exposure to temperatures elevated above 20 °C between mid-August and mid-September as they did pre-HCC, but experience a lower maximum temperature than occurred historically. This is based on water temperatures present at Central Ferry in the early to mid-1950's, prior to construction of the HCC or the lower Snake River reservoirs.

This statement above concerning the current temperature exposure of Chinook appears to refer primarily to the temperatures experienced from the mouth of the Snake River through Lower Granite Reservoir. The basis for this statement is not given. There is no indication what is really implied by "similar." The comparison appears to be made between current temperatures from mid-August to mid-September vs. the temperatures in the mid-1950's (1955-1958). Elsewhere, IPC argues that temperatures in the mid-1950s are not suitable in establishing the baseline for the HCC because of the extensive development that had occurred in the Snake River plain. This argument also holds true for the lower Snake. Temperatures in the mid-1950's were undoubtedly significantly altered from historical values. In addition, a comparison with current Snake River temperatures is a comparison against the river modified by significant water releases from Dworshak Reservoir. Possibly Groves et al. (2007) are trying to establish that the addition of HCC to the Snake River didn't further alter the adult migration timing that was observed in the mid-1950s. However, water temperatures measured at Central Ferry (downstream of Lower Granite Dam, RM 83.2) in the mid-1950s with numerous pre-existing IPC dams other than the HCC, compared against current temperatures that represent effects of Dworshak releases, long-term global warming, and the addition of HCC is not a reassuring basis for claiming that temperature exposure and adult migration timing have not changed. If anything, it argues that the combination of climate change and HCC have negated the beneficial effects of the Dworshak releases, keeping the Snake River at the mid-1950s status as a thermally perturbed river.

Groves et al. (2007, p. 1)

Dam and as a result of the Hells Canyon Complex. Generally, upstream of the Hells Canyon Complex is warmer during the spring and summer months relative to the pre-development era (pre-1860). This thermal inertia influences the magnitude and duration of the thermal shift downstream of Hells Canyon Dam that was created by the operation of the HCC. This paper discusses what the effect of those changes are to fall Chinook

Is the "period of exposure" meant to imply that the accumulated time of exposure to temperatures >20°C is equal for the two different eras? It is likely that daily temperature fluctuation in the predevelopment period (free-flowing river) was greater than today with the reservoir system. Without some context, a statement such as this does not carry much meaning.

The Central Ferry water temperatures that were measured between 1955 and 1958 occurred before the HCC or lower Snake reservoirs were constructed. The use of Snake River water temperatures from the mid-1950s is not highly reflective of natural temperatures for the river given the high level of development that had already occurred in the Snake basin by this time. Also, there were 13 major hydropower dams on the Snake River above the HCC that preceded 1958. Of these dams, 11 of the 13 are owned by Idaho Power Company. (See notes for details). In addition, the current temperatures between mid-August and mid-September referred to are significantly influenced by coldwater releases from Dworshak Reservoir. So, a comparison of cooled lower Snake River temperatures against an elevated baseline thermal regime from the mid-1950s (which was noted as having greater maximum temperatures than the current regime is not a good basis on which to argue that there has been no apparent shift in adult migration timing. Both temperature regimes likely represent elevated thermal conditions and consequently, probably would both be linked to alterations in adult migration timing or at last altered thermal exposure during migration from pre-development.

Central Ferry water temperatures from 1957 and 1958 were very similar to those taken at Oxbow in the same years (USACE 1999, see figures in notes). If these temperatures are the same and the Central Ferry temperatures reach maxima of 25°C by mid-August (Groves et al.2007, p. 18), and the current temperatures upstream of HCC are warmer than pre-1860's temperatures (Groves et al. 2007, p. 1, p. 9), then it seems reasonable to conclude that temperatures throughout the entire Snake River mainstem in the 1950s were higher than before significant development.

p. 39 Groves et al. (2007) state:

If migrating adult fall Chinook salmon were to remain in the vicinity of Ice Harbor Dam (close to the mouth of the Snake River), it is conceivable that they could be exposed to temperatures ≥19.0°C for about 46 days (with a maximum mean temperature of about 22.0°C). However, as has been discussed earlier, migrating adult salmon have been observed to quickly move through these areas (Peery et al. 2003). Similarly, if adult fall Chinook salmon remained in the vicinity of Lower Granite Dam, it is conceivable that they could be exposed to temperatures of approximately 19°C for about 28 days (with a maximum mean temperature of about 18.5°C). It generally takes adult salmon only a couple of days to navigate through the Lower Granite Reservoir and into the vicinity of the lower Clearwater River and the lower Hells Canyon Reach of the Snake River. It may

There have been numerous references to migration blockages that have occurred at temperatures of approximately 21-23°C (McCullough et al. 2001). This tends to be exacerbated when dissolved oxygen concentrations are low. Other studies have shown that impoundments can facilitate upstream passage rate by reducing flow velocities. However, temperatures >20°C are also responsible for significantly reduced rates of adult travel to spawning grounds (Goniea et al. 2006, see notes). In addition, maximum swimming speed in PIT-tagged Chinook was observed at 16.3°C (Salinger and Anderson 2006, see notes). Slowed migration is associated with cumulative effects of the hydrosystem and impairs migration success (Naughton et al. 2005, see notes).

<u>Pre-spawn mortality</u>

b. *Pre-spawn mortality* – Some level of pre-spawning mortality among anadromous salmonids is common. There is evidence that adult salmon in hatchery holding environments exposed to prolonged periods of water temperatures > 19 °C could be subject to significant pre-spawn mortality. In hatchery holding situations, the mortality is usually associated with increased susceptibility to disease. However, fish-to-redd ratios documented in the Snake River do not suggest excessive pre-spawn mortality of fall Chinook salmon. It may be that the non-confined environment of a large river under a naturally declining thermal regime and the availability of cooler refuge makes fish less susceptible to disease and mortality. In addition, the HCC has cooled late summer outflows relative to levels associated with the inflow temperature and the operations of Dworshak Reservoir substantially cool areas associated with Lower Granite Reservoir and create thermal refugia during the early pre-spawn environment such that conditions prevalent today are better than conditions prior to the HCC.

IPC acknowledges that holding temperatures >19°C have been noted as causing excess mortalities. This contention is supported by Berman and Quinn (1989).

IPC implies that the Snake River below HCD is not subject to this impact because (1) temperatures there are not excessive or not "prolonged," and (2) diseases that often accompany or are linked to thermal death are more associated with hatchery situations. Temperatures below HCD during the holding period (approx. September to December) have temperatures >19°C (and >20°C as the ODEQ temperature standard) during September and to mid-October. While disease incidence is more common in hatchery environments than in the wild, diseases are certainly known from stream environments and are thought to be much more common than typically assumed (Hershberger 2002, cited in Ruggerone 2004).

A large river has a lower contagion factor due to lower density of fish than would be typical of hatchery environments. However, passage through dams concentrates fish in fish ladders where salmonids come into contact with many fish species and diseases. This has long been considered to be a key mechanism for disease propagation. Warmwater disease incidence and proliferation increase significantly at temperatures above 15°C. Concentration of fish into thermal refugia in a warmed river also increases risk of disease spread. In addition, historic fall Chinook population densities were far greater than those of today so population density needs to be higher in the future and less susceptible to warmwater disease. Dam operations should not be in the position of claiming credits for maintaining low population densities in the interest of reducing disease transmission. It is more appropriate to maintain temperatures within standards and near historic values and timing to ensure low disease levels.

Groves et al. (2007) state:

p. 39

> Within the Snake River, adult fall Chinook salmon can pass into and hold within several different river reaches, all having different thermal characteristics. As well, if adult fish within the Snake River are experiencing less than optimal water temperature, they have the ability to freely move among the various reaches and seek out thermal refuges. Fish

p. 39

> cooler temperatures (generally a maximum of approximately 15°C). Near the confluence of the Snake and Clearwater rivers, there is a significant cool water refuge available for upstream migrating adult fall Chinook salmon, largely because of the cooling effect of releasing water from Dworshak Reservoir. The *earliest* fish entering the lower Hells Canyon Reach of the Snake River could conceivably experience water temperatures ≥19.0°C for about 32 days (with a maximum mean temperature of about 22.0°C). Again,

if these fish experience thermal stress, they could move back downstream into a more amenable thermal refuge near or in the Clearwater River, or could even continue moving upstream into areas where other thermal refuges exist. For example, water entering the Snake River from the Grande Ronde River (Snake RM 168) tends to be <19.0°C by 1 September, and is cooling rapidly. There are also similar cool water refuges further upriver near the mouths of the Salmon and Imnaha rivers, and at many other smaller tributaries throughout the upper Hells Canyon Reach (such as Divide Creek, Zig-Zag

However, Connor et al. (2005, see notes) and Clabough and Stuehrenberg (2006, see notes) state that thermal refugia are limiting in the contemporary fall Chinook spawning areas. Berman and Quinn (1991, see notes) state that the availability of thermal refuges can affect population productivity. Also, even if cooler refuges exist in certain points in the Snake system, the need to hold there until late in the season prior to spawning and then to migration upstream to re-establish spawning sites upstream may tax the ability of the fish to adapt to the spatial limitation in refuge availability.

From the compilation of small tributaries cited by Groves et al. (2007) it is unclear that the fall discharge provided by these tributaries would be significant enough in volume and cold water to provide a thermal refuge and whether if these flow entry points that might exist are sufficiently shielded from mixing with the mainstem flow that they create a significantly large refuge. It is likely that these represent only potential points of refuge assuming flows are not diverted or that water temperature are not heated from land use practices. I believe that it is the intent of EPA that the mainstem would achieve summer temperatures ≤ 20°C but in the process of specifying this general temperature limit, there should be refugia that are well-distributed to provide temperatures that are more nearly optimum for salmon holding. IPC should not be counting on fall Chinook to hold for prolonged periods in the Clearwater, only to dash up to the HCD to spawn (see Keefer et al. 2004, in notes). It also cannot promote temperatures >20°C and then rely on thermal refugia that may or may not be present to compensate for the lack of temperature regulation.

The 7-DADM temperature of 13°C for spawning as adopted by Oregon and Idaho is based on the 7 days following October 23 (the assigned average first day of spawning). This running average of the daily maximum temperature is based on October 23-29. This means that the temperature on October 23 might be, for example, 14.0°C and on October 29 it might be 12.5°C. If the average daily maximum for this 7-day period is ≤ 13°C, it would meet the standard. This system of temperature accounting permits IPC to keep temperatures higher for longer in the fall than seems justifiable. That is, spawning between October 23 and October 26 is apt to be at a temperature >13.0°C. Achieving a temperature of 13°C on October 23 ±3 days (i.e., an average of October 20-26) would seem more appropriate.

Groves et al. (2007, p. 56)

treatment. These eggs had a final mortality of 13%, and had been initially exposed to a water temperature of 15.6° C for 5 days. Unfortunately, as with all other studies, no replicates were maintained within any temperature treatment. Therefore, there was no possibility to test for statistical differences due to treatments. However, the data from the spawning of 24 September strongly suggest that final mortality is not so much due to the actual thermal exposure, but more to the length of time that embryos are exposed to an elevated water temperature (Figure 11).

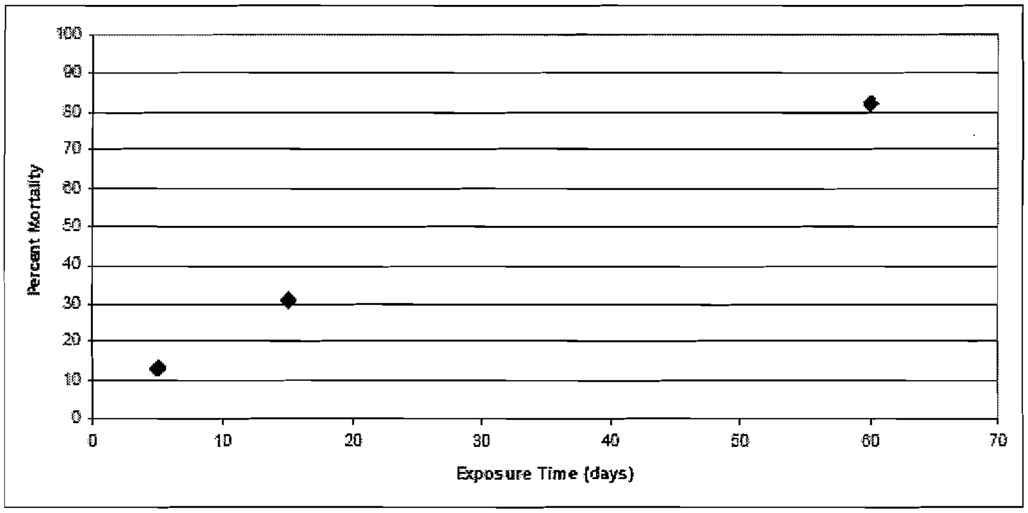

Figure 11. Percent mortality of Chinook salmon embryos dependant on exposure time (days) to water temperature of approximately 15.6 degrees C (data from Healey 1979).

Groves et al. make two points in the material above from p. 56 concerning the Healey (1979) paper. On this paper and on many others they lay the criticism that there are no replicates for temperature-exposure combinations. It is definitely desirable to have replicates but it is far from a fatal flaw in these studies not to have them. For example, if a study examined the response to 3 constant temperatures, 10, 13, and 17°C, with replication and it showed that at 17°C there was 100% mortality but at 13°C mortality was 5%, is this better than a study that showed the response to 10, 12, 14, 15, 16, and 17°C without replication? In the second study it might be revealed that there was 5%, 15%, and 30% mortality at 12, 14, and 15°C, respectively. This study provides more information than does the one with replication.

Groves et al. (2007) are correct in pointing out that thermal effects are a function of both temperature and exposure time. This is not new information, however. It is the basis for all incipient lethal temperature studies that have been done. However, temperature effects during incubation have generally been studied using constant temperatures. Groves et al. point out the effects of exposure times using the Healey (1979) data at 15.6°C. According to their graph, percentage mortality increases from approximately 12% at 5-days exposure to 31% at 15-days exposure, and 83% mortality at 60-days exposure at 15.6°C. If the constant incubation temperature were raised to 16.5°C, one would expect higher percentage mortalities at all exposure times. Groves et al. might argue that mortalities in a 1-day exposure as opposed to 5-day are minimal and of no consequence to the listed population. However, above the optimal incubation temperature of 13°C set by EPA, incremental increases in mortality were anticipated. IPC counts on only a 0.2°C reduction per day which for all intensts is a relatively constant temperature over the initial 5 days. It is for this reason that an incubation temperature toward the high end of optimal was selected as a threshold. EPA recognized that temperatures decline during the initial incubation period, are relatively stable during the middle incubation period, and rise in spring for the Pacific salmon. It would not be acceptable to maintain a temperature of 13°C during winter, even though it is identified as within the optimum range, because of the implications in emergence timing, which are dependent upon acquiring needed thermal units to emigrate at ecologically opportune times. Also, excess mortalities are avoided by application of an initial spawning temperature of 13°C (upper end of optimum). If temperatures were as benign as implied by IPC between 13 and 16.5°C, earlier spawning at these temperatures could occur prior to October 23.

Groves et al. (2007, p. 20).

survival of adult Chinook salmon prior to spawning. All of the pertinent literature available pertaining to Chinook salmon pre-spawn mortality in relation to water temperature is based on studies of spring or summer Chinook salmon (Coutant 1970, Becker 1973, Lindsay et al. 1989, Berman 1990, Jensen et al. 2005, Jensen et al. 2006). The actual cause of death in most all cases is outbreak of disease associated with long exposure times (as much as seven weeks) at elevated water temperatures (≥19.0°C) and fish being held in stressful conditions and in close contact with each other (e.g. hatchery holding ponds).

The statement above by Groves et al. (2007) overlooks much available literature on pre-spawning mortality of fall chinook. Much pre-spawn mortality data are available from California rivers and is cited by State of California (2004, see notes) for the Lower Feather River and other California rivers. Although hatchery conditions can exacerbate disease effects, it is inaccurate to imply that pre-spawning mortality is a problem only where fish are being held under hatchery conditions.

Brown and Geist (2002) studied the energy expenditure of Klickitat River fall chinook. They found that the extreme energy demands on these fish combined with delays in spawning could result in inability to spawn. Given the far greater energy demands on Snake River fall Chinook spawners, it is likely that bioenergetic concerns on spawning ability would be greater. This argues for moderated pre-spawning and migration temperatures to improve the spawning success.

Gamete Viability

c. *Gamete viability* – A through review of the literature demonstrates that studies often cited to suggest reduced gamete viability as a result of prolonged exposure to warmer temperatures should not be cited as supporting literature. The studies typically were not designed to address the question. One study that could be cited as supporting evidence (Jensen et al. 2006) did not hold adult Chinook salmon in a declining thermal regime typical of a riverine environment, but rather exemplified relatively long-term (40-days) exposure to elevated water temperatures. In addition, the control group held fish in a constant thermal environment of between 8 and 9 °C, which cannot be compared to a declining thermal regime under more normative environments. Based on the available information, it is difficult to conclude that the HCC has had an adverse effect on development of gametes in returning adult fall Chinook salmon.

The comment that any study is invalid that does not utilize a declining thermal regime to examine the effect of temperature on gamete viability is itself invalid. Holding by fall Chinook prior to spawning occurs during September and October and into December in the Snake River. Temperatures do not significantly decline from summer to October 1 below HCD. From July 9 to September 27, 1998, there was an 80-day period in which the temperature of the Snake below HCD varies from 20 to 23°C. Between September 1 and October 10, temperatures vary from approximately 22 to 18°C. The value of the Jensen et al. (2004) study on pink salmon is to show that temperature exposure for a lengthy period prior to spawning can negatively influence gamete viability.

Groves et al. (2007) did not cite the study by Mann and Peery (2004, see notes) that showed that Chinook exposed to temperatures as high as 23.6°C during migration had a high incidence of embryo mortality. Other reports cite a large body of literature indicating impact of rearing temperature on gamete viability (e.g., Berejikian 2005, see notes; also see references of Berejikian).

Disease Susceptibility

d. *Disease susceptibility* – Similar to the findings discussed under pre-spawn mortality, adults held in confined hatchery environments under prolonged periods of elevated temperature appear to have a greater susceptibility to disease or fungal infections. How this pertains to free-ranging adults is uncertain. However as discussed above, fish-to-redd ratios do not suggest a high level of pre-spawn mortality below Hells Canyon Dam.

It is probably true that disease problems under hatchery conditions are more severe and frequent than for wild populations. However, it is still valid to use known relationships between temperature under hatchery and natural field conditions relative to disease outbreaks to establish precautionary thresholds to be applied to natural populations. There is always uncertainty concerning application of any instance of a relationship between water quality conditions and biotic response to other instances of similar water quality conditions, whether it be in hatchery or natural environments. However, the number of cases documenting the significance of high temperatures in relation to outbreaks of warmwater diseases in salmonids necessitates assuming that nuances such as differences in populations among a single species and differences in precise temperature fluctuation patterns (e.g., constant, increasing, declining) during exposure are subservient to the overriding issue of exposure to high temperatures, especially when the level of temperature variation is not large.

Groves et al. (2007) pointed to the Snake River temperature history at Central Ferry below the site of Lower Granite Dam as a useful record for the period 1955-1958. Central Ferry water temperatures for 1958 reached at least 24°C and probably 26°C in 1958 (USACE figures, see notes). In addition, Richards (1959 and 1960, see notes) reported a high incidence (77.0%) of columnaris in Snake River fall Chinook in 1958 and in 1959 (or 1960) (62.2%).

Fish-to-redd ratios were cited numerous times as a key piece of evidence that pre-spawning mortalities were low below HCD. The premise of this statement is that if there is a difference between the ratios of fish counts at Lower Granite Dam and redd counts in the Snake River mainstem and tributaries among years, then one might infer that this is attributable to variation in prespawning mortality. Numbers of adults counted passing the dam and numbers of redds both are related to the total escapement. Adult counts should be corrected for fallback and the number of females would be most highly related to the number of redds. There are a number of reasons why this is not a strong piece of information for use in claiming no variation in pre-spawning mortality:

(1) The calculation of fish counts at the dams has a significant level of uncertainty due to a variety of factors, such as observer error and variation in detection rate (e.g., see Brown and Newton 2001, see notes).
(2) There is a variable level of fallback, which can be related to flows and temperature.
(3) Fish counts may include jacks, which can assume variable importance in spawning, depending upon the availability of older males in the population. The percentage of jacks in the spawning run has varied from as much as from 15 to 50% of the run, based on the 1955 to 1958 data from IDFG for fall Chinook passage above Oxbow Dam. The number of redds would depend significantly on the percentage of jacks.
(4) There is annual variation in male/female ratio among years (Howell et al. 1985, see notes).
(5) A female can dig more than one redd. It is uncertain to what extent the number of redds per female is constant from year to year.
(6) It assumes that the percentage of females in escapement that will spawn is the same from year to year.
(7) In some years the ability to detect redds is low relative to other years due to turbidity. There could be a greater concentration of spawning in some years in deep water vs. shallow water. Factors such as this can broaden the fish-to-redd

ratios observed from year to year, but can also create enough variation in the ratio so that variation due to pre-spawning mortality cannot be effectively detected.

(8) *When all of these data are compiled and analyzed relative to the total number of adult fall Chinook salmon allowed to pass upstream of Lower Granite Dam (with fallback and over-counting at the dam taken into account), the resulting fish to redd ratio has averaged 3.2 (range 2.0-4.2, data from 1993-2006). This comports well with (or better than) estimates of fish to redd ratios for the Hanford Reach of the Columbia River (3.0-16.0), where pre-spawn mortality is not considered to be a problem (Visser et al. 2002), and has never been reported as "excessive". (Groves, Chandler, and Myers 2007).* If the fish-to-redd ratio averages 3.2 and is 3.2 one year, but is 4.2 the next year, it is possible that pre-spawning mortality could be 0% the first year and 23.8% the next year due to temperature conditions. This is calculated as 420 fish pass the dam but 100 die (i.e., 23.8%), and the remaining 320 produce 100 redds (fish-to-redd ratio observed is 4.2). However, if 320 fish pass the dam with no mortality and produce 100 redds, the fish-to-redd ratio is 3.2. This level of pre-spawning mortality could cause this degree of variation in fish-to-redd ratio. This level of variation could also be entirely due to variation in counts of either fish passage or redds or both. If 10% of the fish passing the dam are not counted, they could all be mortalities due to temperature conditions, yet the ratio could remain unchanged. If there is a 10% error in identification of males and females such that there are really 10% more males than reported one year vs. the next, the fish-to-redd ratio would be higher than expected for no apparent reason.

Spawn Timing

e. *Spawn timing* – There is no evidence that spawn timing has been greatly altered in the Snake River when comparing pre-HCC spawn distribution to that of the present-day Hells Canyon spawn distribution.

Evidence for the pre-HCC spawn distribution comes from the IDFG spawning reports from 1958-1960 (Richards, IDFG, see notes). These reports show that about 1% of the fall Chinook run passed Oxbow Dam site in August, but that 67% were transported past Oxbow in September. Passage in September accounted for 23.5% of the total run in 1957 and 51% of the run in 1959. Spawning ground counts were made on November 10 and 11. Consequently, there is no real indication when spawning actually took place. It could be that the counts were made on November 10 and 11 to ensure being able to detect the full spawning run in a single pass. These data then do not indicate the distribution of spawning, but they do indicate the dates of passage at Oxbow Dam.

Groves et al. (2007, p. 40) also state the following relative to spawn timing:

With respect to delay of the actual spawning activity, there is evidence that a shift toward earlier spawning might be feasible if the river corridor could be cooled substantially. However, it would likely be very difficult to cool the river enough to make a reasonable shift in spawn timing. Data from 16 years of spawning surveys in the Snake River indicates that initial spawning is not consistently initiated because of either photo period or water temperature (Table 3). In the upper Hells Canyon Reach, the earliest spawning

In addition, they state (p. 43):

> Further, spawn timing appears to be strongly associated with a declining thermal regime and likely other environmental cues that are consistent regardless of water temperature, such as photoperiod, rather than a specific water temperature.

Spawning may be associated with a declining temperature regime, but Groves et al. (2007) do not present any evidence that this is more significant than initial spawning temperature. Tables presented by these authors indicate that temperature is highly significant in initiating spawning. Table 3 (p. 41) shows that over the period 1991-2006, in 13 of the 16 years, spawning in the upper Hells Canyon Reach commenced at 7-day mean water temperatures of <16.6°C and after October 18. By averaging day number for these 13 years, one can calculate a mean date of first spawning of approximately October 26. Using the entire 16-year data set, the mean date of first spawning was October 23. There were only 2 instances of early (prior to October 18) spawning at higher temperatures (October 9 at 17.3 and 19.1°C). No evidence was provided that temperatures on October 9 were declining to produce spawning. It is not uncommon for Chinook spawning to be noted at 19°C (see McCullough 2006 compilation of literature; also State of California 2004, see notes), but this is no indication that survival would be high. If the Geist et al. (2006) study results are used, one would infer very high mortality at these initial temperatures. Initial spawning as late as November 11 may indicate delayed spawning due to a variety of reasons. It would be an adaptive advantage to delay spawning until temperatures decline to favorable survival temperatures. If it takes a lengthy period for temperatures to decline sufficiently, it is also adaptive for the fish to spawn at the earliest opportunity to provide the greatest chance of emerging as early as possible. This would represent a tradeoff between spawning temperature and date. In the lower Hells Canyon Reach of the Snake River, in 15 of the 16 years, the mean water temperature during the 7 days prior to first observed spawning was 13.5°C. Only in 2001 did first spawning occur at high temperatures in the lower HC Reach (i.e., at 17.9°C). In 2001, first spawning occurred on October 9 in both the lower and upper HC Reaches at high temperatures. An explanation for this is uncertain. Possibly passage difficulties depleted the Chinook energetically, creating an immediate need for spawning prior to death. In any case, photoperiod is not a likely reason for variation in spawning times because the latitudes involved in the Snake River are not significantly different.

In the Clearwater River (see Groves et al., Table 4, p. 42), the mean water temperature at Lewiston for the 7-day period prior to first spawning was 13.1°C for four years having temperature data. The spawning initiation occurred between September 23 and October 1 in these years. Temperatures in the Clearwater River measured at Peck were approximately 2°C colder than at Lewiston. It is difficult, without more information, to know where the fall Chinook were holding prior to spawning and which temperature data set (i.e., either Lewiston or Peck) applies better to the environment in the holding area and spawning area. Despite this issue, it appears that spawning in the Clearwater River is initiated more frequently at earlier dates than in the Hells Canyon Reach and at temperatures <13°C. For all years for which first spawning dates were indicated, a conversion to day number, averaging day numbers, and converting back to date reveals that first spawning in the Clearwater was approximately October 3 on average.

First spawning of fall Chinook in the Grande Ronde River occurred at an average water temperature of 10.6°C for the 10 years of data between 1992 and 2006 having water temperature data available (Groves et al. 2007, p. 42). Water temperature data were based on the 7 days prior to spawning (whereas the Oregon and Idaho rules use the trailing 7-day period). First spawning dates in the Grande Ronde ranged from October 9 to October 26 for the years having water temperature data. Fall Chinook apparently are not choosing the option of spawning earlier at temperatures >13°C in either the Clearwater or the Grande Ronde. In the Clearwater, spawning at an average date of October 3 provides fall Chinook the advantage of advanced emergence and more lengthy rearing opportunity to achieve a large size prior to either emigration or overwintering, depending upon the life history alternative utilized (age-0 or age-1). In the Grande Ronde, the fact that fall Chinook spawn in mid-October at optimum initial temperatures (i.e., <13°C) may indicate that these fish are able to emerge at times appropriate to enable emigration in a timely manner at this point in the river and still spawn as late as they do. Without knowing the rate of river warming in the spring or the thermal accumulation during the incubation period in the Grande Ronde relative to that in the Snake River below HCD, it is difficult to compare the tradeoffs involved in initial spawning dates vs. initial temperature.

In summary, from information provided by Groves et al. (2007) it appears there is further support to the idea that temperatures <13°C are preferred as initial spawning temperatures. Also, it appears that spawning date can be advanced as much as 20 days by lowering temperatures from 15.1°C (average initial temperature for spawning in 13 of 16 years in upper Hells Canyon Reach) to 13.1°C in the Clearwater. Another way to view this is that the thermal shift has been approximately 3 weeks below HCD. If we achieve threshold spawning temperature standards three weeks earlier or if we restore the thermal regime by removing the thermal shift, spawning would be able to commence up to 3 weeks earlier.

Groves et al. (2007, p. 14).

As discussed later (section 4.5), there is little evidence that spawn timing has changed appreciably today as compared to spawn timing prior to the construction of the Hells Canyon Complex below Swan Falls Dam. Spawning was initiated in early October and extended over a relatively prolonged period through early December, with peak spawning occurring around the first week of November (Zimmer 1950). This is very similar to what has been observed today in the spawning area below Hells Canyon Dam. This

It is stated on p. 14 of the white paper that there is little evidence of a change in spawn timing. Zimmer (1950, see notes) noted that spawning started in late September. This is different from the October 23 date established for the IPC below HCD. Groves et al. (2007) stated that peak spawning occurred in the first week of November. Counts in 1949 by Zimmer (1950) revealed a nearly equal number of redds on October 18 as on November 22 from aerial surveys in the Swan Falls to Murphy Bridge reach. Redds counted on the first survey date were not included in the later count. This would indicate that all redd construction in the weeks prior to October 18 were equal to the redds constructed after October 18. This doesn't appear to indicate that early November is a peak in spawning. In 1947 there appears to be better evidence of a spawning peak in early November. However, 26% of the redds deposited between Swan Falls and Weiser surveyed by plane were deposited prior to October 17. Again, this indicates considerable spawning at an earlier date than the October 23 date set for IPC below HCD. The actual date of first spawning is given as late September. The magnitude of spawning this early is difficult to infer from the tables of redds by date for 1947 because the counts made prior to October 17 were made by ground or boat observation, which was noted as being extremely unreliable compared with the plane. In 1949 the first survey date was October 18 and half the total counts were observed by this date, which would indicate that substantial spawning occurs prior to October 18. By contrast, the earliest observed spawning between 1991 and 2006 cited by Groves et al. (2007, p. 41) was October 9 in 2000 and 2001. The mean date of first spawning for this 16-year period was October 23 below HCD. This appears to indicate that first spawning in the reach from Swan Falls to Weiser started approximately 4 weeks earlier based on data from Zimmer (1950).

<u>Incubation Survival</u>

f. *Incubation Survival* – Experiments based on constant and declining thermal regimes differ markedly in their results with respect to both ultimate survival and size of fry at emergence. To assess the thermal requirements of incubating eggs in a natural declining thermal regime, Olson and Foster (1955), Olson et al. (1970) and Geist et al. (2006) are the most applicable findings to conditions experienced by Snake River fall Chinook salmon. These studies suggest that eggs spawned at initial temperatures of between 16 °C to16.5 °C do not experience different levels of mortality from those eggs spawned at temperatures as low as 13 °C. At temperatures above 16.5 °C, mortality of incubating embryos substantially increases. The thermal shift that occurs below Hells Canyon Dam delays cooling of water temperature in the fall and significantly advances the emergence timing of juvenile fall Chinook salmon closer to what occurred historically in the primary production areas upstream of the Hells Canyon Complex. The HCC is now more suitable for the expression of an Age-0 fall Chinook salmon life history than it was before construction of the HCC. The elevated winter base temperatures also contribute to the advanced emergence timing relative to pre-HCC.

Groves, Chandler, and Myers (2007) dealt with the Olson et al. (1970) data that provide evidence of negative effects of declining temperature regimes with lower initial temperatures than reflected in Geist et al. (2006) by merging data from Olson and Foster (1955), Olson et al. (1970), and Geist et al. (2006). Although Groves et al. (2007) emphasize the importance of having statistics of variance based on replication with which to test the differences in biological response to temperature, their method serves only to create ambiguity by artificially expanding the range in response and making differences non-significant at an $\alpha = 0.05$ level (a significance level that places the burden on the fish and is not precautionary). Merging data from different studies is not a valid means of creating replicates. This amalgamation process indicated that a temperature of approximately >16.0°C is needed in a declining temperature regime to produce significantly greater fry mortalities. Although statistical tests are often desirable, it is not appropriate to obliterate results that differ from one test by averaging it with results from other studies. The Olson et al. (1970) study itself states that it discounts its results from its November 30 test initiation date due to highly variable outcome.

The October 30 test initiation date of Olson et al. (1970) is the one most similar to spawn timing occurring below HCD. It is reasonable to interpret these results as producing a significant increase in mortality between initial temperatures of 56.6 and 58.6°F. Groves et al. (2007) are correct that there was a single day upward tick in temperatures by approximately 0.6°F that could be interpreted as creating initial temperatures that were actually about 57.2 (14.0°C) and 59.2°F (15.1°C).

In the November 14 test, mortality increased approximately 50% over the temperature range from 13.9 to 16.2°C. Mortality then more than tripled as initial test temperature increased to 17.3°C.

Olson et al. (1970) discarded the November 23 test data. It is not clear whether Groves et al. (2007) averaged in these values with the other data or not.

The Olson et al. (1970) data for a December 8 initial test exposure indicated that in the comparison of egg lots at initial temperatures of 12.3 and 13.4°C, percentage mortality (eggs plus fish) doubled with this increase in initial temperature and remained doubled as initial temperatures increased to their maximum level of 15.0°C.

Groves et al. (2007) state that the HCC is now more suitable for expression of age-0 fall Chinook life history than before construction of the HCC. This is based on the contention that:
(1) The combination of spawning time and temperatures up to 16.5°C are ideal initial spawning and incubation temperatures; spawning that occurs before October 23 at higher temperatures constitutes a small percentage of the population and can be ignored; achieving a temperature of ≤ 16.5°C by October 23 is adequate for timing of spawning initiation and temperature regime; there has been no delay in spawning initiation from either the 1950s or prior to significant development of the Snake River system (i.e., prior to 1900),
(2) Any temperatures exceeding standards can be excused by either high air temperature exemptions or low flow exemptions,
(3) Biological consequences of further climate change predicted for the Snake River for the next 50 years by the majority of professional climatologists can be either ignored or can be excused by an exemption. Unfortunately, climate change and river temperature increases that have been documented over the past 50 years have caused fall Chinook and other salmonids to exist closer to thermal tolerance limits and to shift their spawn and emergence timing to compensate.
(4) The thermal shift that occurs in the fall is beneficial because it results in prolonged warm temperatures that produce a higher rate of embryo development.
(5) There are only steadily declining temperatures after October 23 and momentary peaks exceeding 16 or 16.5°C do not occur. Groves et al. (2007) were critical of the

Olson et al. (1970) study for a brief temperature uptick after test initiation in the declining temperature regimes used in their study but there is no guarantee that upticks will not occur in the Snake River.

This reasoning discounts studies on effects of constant temperature incubation with the claim that only declining temperature studies are relevant to the Snake River. Thermal effects are a result of temperature and duration of exposure. Exposure to a declining temperature can easily be parsed into successive days under a series of progressively changing exposures. If a constant temperature study shows that a temperature 16°C is harmful during a 40-day exposure, there is reason to believe that the level of harm is less with a 1-day exposure, assuming that 16°C does not result in 100% mortality in 40 days. It is possible that a 16°C temperature for a 1-day exposure has a negative effect that is small enough that to demonstrate this at $p<0.05$ would require a large sample size, something not often provided in laboratory testing. The process of setting a protective standard, as adopted by EPA, was to make use of the abundant literature available on incubation effects and to emphasize temperatures known to provide a high level of protection, not to entertain small percentages of impact. Olson et al. (1970) data show significant impacts at initial incubation temperatures in declining temperature regimes above approximately 14.4°C and possibly lower. Constant temperature studies reveal impacts at lower temperatures, notwithstanding the deficiencies pointed out meticulously by Groves et al. (2007).

p. 60. Groves et al. (2007)

test temperatures (Figures 12 and 13). However, it should be noted that a constant incubation temperature of 5.0° C (or any temperature for that matter) does not occur in nature where Chinook salmon embryos incubate.

Although it is a valid point that we must be concerned with the daily fluctuations in temperature as well as the trends in temperature (increasing and decreasing with season) and daily and seasonal minima, means, and maxima, Groves et al.'s (2007) criticism of the utility of studies on constant temperatures is unfounded. If we were to discard all constant temperature studies as invalid for application in the field because temperatures vary in nature, we would have very little data available for regulating heat loading. Moreover, in the case of the Snake River, daily temperatures do not fluctuate dramatically like they do in many other stream settings. Consequently, constant temperature experience is more appropriate in the Snake River than in smaller rivers. In addition, IPC is contemplating decline rates of only 0.2°C/d, which represents nearly constant temperature in a 5-day period.

If constant temperature data are of no value in predicting survival in the field or in setting protective standards, it is equally difficult to imagine how experiments in varying temperatures would produce greater certainty. There are an infinite number of temperature variations that could be studied. If daily temperature fluctuation were ±1°C in one experiment, then it could be criticized that this is nearly constant and does not apply to cases where temperature fluctuations are ±4°C. It is also possible that there should be a daily fluctuation embedded within a multiday decline. Temperatures in the field can also decline for several days, followed by several days of increase, followed by an overall seasonal decline. A comment such as attributed to Combs (1965) (i.e., "The conditions imposed upon the sockeye salmon eggs in these tests would rarely be duplicated in nature or in artificial propagation procedures") could as well be applied to any laboratory temperature regime set up. One objective of a constant temperature regime is to know exactly what to attribute a response to. Significant changes in mortality at specific temperature thresholds are important reasons for setting standards.

p. 62. Groves et al. (2007)

> to cooler temperatures. Finally, there was little evidence that differences in thermal adaptation existed between the two Chinook stocks. However, the authors continually brought up in their discussion the supposition that local stocks are adapted to local thermal conditions.

p. 64. Groves et al. (2007)

> the natural habitat. The authors also noted that the data provided insight as to the variation among Pacific salmon with respect to how water temperature affected embryonic development rate, survival, and fry size and weight. A very telling quote from the conclusions was, **"Because the species showed different trends in emergence timing with respect to changes in development temperature, it seems reasonable to infer that these different trends reflect adaptive variation in the species' response to environmental temperature during development"**. And finally, the authors noted, **"Population-specific differences in development can also exist, and populations that spawn in extreme environments can probably be expected to have different rates of development and survival than populations in more moderate environments"**. This paper establishes a very good base for understanding that not only are there species-specific differences in how Pacific salmon are differentially adapted to various thermal environments, but also how population-specific adaptations are likely.

Groves et al. (2007) reviewed Beacham and Murray (1989 and 1990) and concluded that population –specific adaptations are likely. Beacham and Murray (1989), according to Groves et al. found no population differences. Both Beacham and Murray papers found differences among species in development rates and other factors. Beacham and Murray (1990) cited Beacham and Murray's (1987) work on chum as showing population level differences in development rate. Even though Beacham and Murray (1990) state that population level differences in survival "can probably be expected" between extreme and moderate environments, significant population differences have not been demonstrated in the literature for any salmonid.

Groves et al. (2007) summarize the hierarchy of biological differences in this manner:

to some extent other Chinook salmon races, are not relevant. Generally there are small differences in thermal responses among stocks and these differences increase from races, subspecies to species and then families of fishes (McCullough et al. 2001). Genetic variation exists within Chinook salmon and other salmonids of the Pacific Northwest, as indicated in classification diagrams constructed by the National Marine Fisheries Service (McCullough et al. 2001). It is clear that based on ***constant*** temperature studies, different

The hierarchy of biological responses to temperature shows finer and finer differences among taxa in a series from fish families, to species, to subspecies, to races, to populations. It is unclear whether Groves et al. (2007) intend to imply that Snake River fall Chinook are more temperature tolerant than Columbia River fall Chinook (a population difference), that fall Chinook are more tolerant than spring Chinook (a race difference), or simply that they are more tolerant than sockeye (a species level difference). Differences at the species level among Pacific salmon are not large, and differences at the population level are much smaller. Although Groves et al. are critical of constant temperature studies relative to application in field conditions, it does not appear that they would believe that constant temperature incubation studies would indicate similarity among populations where declining temperature incubation studies would reveal differences among the same populations.

Groves et al. (2007, p. 62-63)

representative of what occurs in the natural environment cannot be stressed enough. As well, the authors acknowledge that the information provided was mainly for the accurate prediction of hatching and emergence timing, and was of practical interest for managers involved in salmon culture (hatchery environs). The basic design of this work was to

In the end, the authors acknowledged that all of their results were based on data from constant temperature treatments, and did not reflect what would be expected to occur in the natural habitat. The authors also noted that the data provided insight as to the variation among Pacific salmon with respect to how water temperature affected embryonic development rate, survival, and fry size and weight. A very telling quote from

The authors imply that Beacham and Murray (1990) were somehow caught red-handed with a constant temperature study and had to confess that it was only relevant to hatchery environments. This is far from accurate. The authors concluded their paper with a paragraph warning of the implications of their laboratory studies, given the effects of increasing air temperatures and expected water temperature increases on salmon survival during the incubation phase. If this study only applied to fish culture, the authors would not indicate any application to the field.

Effects of Intragravel Water Temperature

g. *Effects of intragravel water temperature* – In Hells Canyon, there is a strong connection between the water column and the redd environment that allows for similar thermal conditions between the two environments. Therefore, the water column conditions provide good metrics for describing the thermal conditions of incubating embryos in Hells Canyon.

Groves et al. (2007, p. 69) reported that "The thermal environment within Chinook salmon redds can be strongly influenced by surface water conditions (Geist et al. In Press)." This statement doesn't specifically indicate that surface water temperatures would be identical to water at egg pocket depth. They also state (p. 69) that "Chinook salmon also tend to spawn where the natural down-welling of surface water into the shallow hyporheic zone occurs (Vronskiy 1972; Leman 1988; Vronskiy and Leman 1991; Geist 2000; Geist et al. 2002; Hanrahan et al. 2004)" and that Chinook predominantly use downwelling zones as opposed to all other Pacific salmon, which use upwelling areas.

Groves et al. (2007) also stated that the Hanrahan et al. (2004) study measured water column and intragravel water temperatures in spawning gravels but not in actual redd locations. This reportedly accounts for the identical temperatures found in redds vs. the warmer temperatures found in general spawning gravels. However, Figures 16-23 provided by Groves et al. (2007) to substantiate a negligible difference between surface and inter-redd water temperatures was derived from "simulated redd sites" (e.g., Groves et al. 2007, Figure 16, p. 70).

The Hanrahan et al. (2004) study shows that in the first month of egg incubation, temperatures in the shallow hyporheic zone averages approximately 0.5°C warmer than the surface water. This study also indicated that potential upwelling zones are far more common below HCD than downwelling zones. "We randomly selected 14 fall Chinook salmon spawning locations as study sites, which represents 25% of the most used spawning areas throughout the HCR." (Hanrahan et al. 2004, p. iii). If Chinook actually spawn exclusively in downwelling zones, it is likely that acceptable spawning areas are very restrictive. This makes potential spawning habitat much more scarce than anticipated. However, if spawning in upwelling areas becomes more common as the population recovers, fall Chinook would then be more subject to water temperatures warmer than surface temperatures.

Hanrahan et al. (2004) was cited as supporting that Chinook "tend" to spawn where there is natural downwelling (Groves et al. 2007). However, Hanrahan et al. (2004, p. 1.2; also see notes) state that "Recent research in the Hells Canyon Reach of the Snake River indicates that warm hyporheic water upwells into fall Chinook salmon spawning areas (Geist et al. 1999; Arntzen et al. 2001)." Also, "Where warm hyporheic water is upwelling into spawning areas within Hells Canyon, it is possible that emergence may occur 2–4 weeks earlier than in spawning areas dominated by cooler surface water." (Hanrahan et al. 2004, p. 1.2). Geist et al. (1999)(as cited by Hanrahan et al. 2004) noted that as discharge decreases as in leading up to spawning, the magnitude of upwelling increases. This appears to indicate that at the time of spawning, the availability of downwelling sites would be more limited.

I could find no statement indicating their view that spawning was predominantly in downwelling areas. It is not clear what the Geist et al. In press document has to say about the universality of spawning in downwelling zones by Chinook and whether this new information overthrows the Hanrahan et al. (2004) study on these points. Geist and Currie (2006, see notes) reported that chum tend to spawn in upwelling areas and chinook in downwelling areas below the four lower Columbia River dams. This may or may not be a universal pattern. However, to the extent that Chinook spawning occurs in upwelling areas, which would provide necessary flow velocities past incubating eggs similar to downwelling zones, a certain percentage of chinook may be incubating at temperatures greater than ambient water column temperatures.

Groves et al. (2007) state:

However, in the Snake River, temperature within the redd environment is generally the same as what is present in the water column, especially during the first few weeks following redd construction. Similar findings have been reported by Ringler and Hall (1975), Vronskiy and Leman (1991), Hanrahan et al. (2004), and Hanrahan (2007), which were based on data collected from artificial redds.

But Hanrahan et al. (2004) presented a table showing a mean temperature increase between the shallow hyporheic and ambient water column temperatures of about 0.3 to 0.5°C during the first month of incubation below HCD. Temperatures may be "generally" the same, but still a 0.3 to 0.5°C difference in mean values is biologically significant, especially when IPC is recommending initial incubation temperatures at 16.5°C when an initial temperature of 17°C results in near total mortality, based on Geist et al. (2006).

Emergence/Outmigration Timing

h. *Emergence / Outmigration Timing* - Fall Chinook salmon emerge earlier today in Hells Canyon than they did historically in Hells Canyon because of the warmer incubation conditions present today as a result of the HCC. Historically, Hells Canyon was a very cold environment and may not have been conducive for production of an Age-0 migrating fall Chinook salmon. The construction of the HCC altered the thermal regime such that emergence timing is now closer to what occurred historically in the production areas upstream of the HCC. During the 1990's, there was evidence that juvenile outmigration was delayed based on their arrival timing at Lower Granite Dam. Migration through the large slack water environment of Lower Granite Reservoir is more likely to explain the delay observed during that time. Recently, there is evidence of an earlier shift in the outmigration timing at Lower Granite. Fall Chinook salmon appear to be migrating earlier and at a smaller size than observed in the 1990's. Why this trend is occurring is uncertain, but may relate in some way to density in the rearing areas as adult returns and natural production has continued to increase.

Groves et al. (2007) state that Hells Canyon was not conducive to production of age-0 fall Chinook historically and that with construction of the HCC, the emergence timing below HCD is now closer to that in the historic main upstream production areas. So thanks to the HCC and the thermal shift and warmer winter temperatures, fall Chinook production and emigration can now follow a subyearling life history and outmigrate at close to the same time that subyearlings did historically.

Statements above about emergence/outmigration timing imply that:
(1) emergence timing below HCD is close to the historical timing from the Marsing Reach upstream
(2) delayed migration timing occurred in the 1990s but is no longer an issue
(3) the slack water of Lower Granite Reservoir is to blame for the delayed emigration
(4) there is a recent trend toward earlier emigration timing.

There are a number of reasons why these statements may not be accurate and making all these assumptions places fall Chinook at risk.

(1) IPC rightfully criticizes the Snake River TMDL process for not considering the significant impact of upstream human activities in altering the thermal regime of the inflow to Brownlee Reservoir. Much of this thermal impact is undoubtedly attributable to upstream IPC projects. Because IPC is so cognizant of the massive changes in temperature of the Snake River, it would seem that it would also recognize the linkage between spawn timing and emergence timing and spawn timing and water temperature. If historic temperatures were altered by human activities dating at least from 1900 and we have only crude estimates of emergence timing from the 1950s, it stands to reason that emergence timing prior to 1900 could have been significantly different.
(2) Hanrahan (2004, p. 1.1) stated that fall Chinook emigrants from below HCD arrive at Lower Granite Dam 1 to 4 weeks later than before the HCC. Hanrahan et al. (2004) state that there is a significant survival advantage to early emigrants because they can avoid the high mid-summer Snake River mainstem temperatures by their earlier migration timing. This implies that there may be a further advantage in an earlier migration timing achievable with better temperature control and earlier spawning.
(3) If the slack water is to blame, IPC has a responsibility to utilize its cold water and its available flow volume at Brownlee Reservoir to adjust temperatures (lower in summer and fall; warmer in winter).
(4) The recent trend toward earlier emigration is largely a product of the age-1 life history that has been produced in the Clearwater River. The Clearwater River was historically not a major fall Chinook producer. The cold waters from this river during the summer due to the releases from Dworshak have created slower summertime growth and the need for overwintering and emigration as 1-year-old smolts in the spring. This artifact of addressing the warm water problems associated with the lower four Snake River dams should not be confused with the problems created by the HCC.

Groves et al. (2007, p. 78).

> rearing and emigration. In the recent past, up to 50% of the subyearling smolts from the upper reach of the Snake River passed Lower Granite Dam by early July, whereas historically it was believed that they were completely out of this reach by the end of June. This apparent delay in emigration is often attributed to later emergence timing than to what is believed to have occurred historically when production was in the Swan Falls Reach.
>
> A more meaningful comparison relative to the effect of the HCC on emergence and emigration timing is to compare pre-Hells Canyon Complex temperatures of Hells Canyon to present day temperature of Hells Canyon. This comparison indicates that the Hells Canyon Complex warmed the incubation environment such that emergence timing today in Hells Canyon is much earlier relative to what it was pre-HCC. Further, post-HCC temperatures are much closer present-day to the historic Swan Falls spawning area.

It is admitted that 50% of the subyearling smolts pass Lower Granite Dam after July, which is during the warmest-water period and results in high mortality. Despite this, it is also stated that this migration timing is better than we would have expected for this portion of the Hells Canyon Reach prior to construction of the HCC. If this is so, we are to simply accept the loss of over 90% of the historic production and in return get a minor improvement in timing for the remaining portion of the run which never was good habitat. This minor improvement in timing, further, likely comes with the tradeoff of higher mortality in the incubation phase if initial temperatures would be pushed to 16.5°C. Global warming that can easily cause further water temperature increases in the Snake River would not be safeguarded under the IPC proposal, but would be chalked up to "unforeseen" climatic extremes. NOAA Fisheries' recovery plan depends heavily on improvement to the habitat, yet IPC intends to make no improvements in water quality in excess of the minimum requirements of the CWA, and further intends to contest even these standards as not being lenient enough.

Groves et al. (2007, p. 80)

> 2. The presence of the HCC has also created warmer over-winter base temperatures in the area below Hells Canyon Dam relative to the pre-development era because of the large volume of 4°C water stored in Brownlee Reservoir over the winter months.

Emergence timing can be controlled by regulation of spawn timing and the temperature regime during the entire incubation period. Currently, temperatures during the fall have been shifted by approximately 3 weeks to later in the season. This likely has caused a later spawn timing. In addition, winter temperatures are cold below HCD. IPC claims that emergence timing has benefited below HCD by the HCC operations, there is additional room for significantly advanced emergence by use of a TCS. For example, the winter temperatures in 2002 have a prolonged period of temperatures from approximately 2.16 to 3.5°C (McCullough, see figure in notes produced from IPC raw data). If Brownlee Reservoir is stratified during the winter with the deepest portions of the reservoir holding the densest water at 4.0°C, it would be possible to effectively raise this water to run through the turbines. Bubbling to mix water at the face of the dam would not be so effective a means to accomplish a transfer of 4°C water downstream because it tends to mix this water with colder surface water.

Juvenile fall Chinook need to rear as they migrate downstream. For those late migrants entering the Snake River downstream of HCD, it shoreline temperatures exceed 18°C, the juveniles tend to avoid rearing along the shore (USACE, Appendix K, see notes). Marginal temperatures tend to be greater than temperatures in mid-channel. However, mid-channel growth opportunities (i.e., food availability) would be expected to be lower than along the shoreline. Consequently, late migration under high shoreline temperature conditions would probably reduce the ability of these fish to grow adequately.

Ehist

Groves et al. (2007, p. 7)

> Data for any particular year may not be complete. When data were incomplete, IPC substituted data from a similar water year or a lower water year. IPC believes this is a conservative assumption as conditions, flow and temperature, would be more critical in a lower water year. For example, if Salmon River daily average temperature was unavailable for 1994, Salmon River daily average temperature from another low-water year, like 1992, was used to develop a complete data record. The logic sequence used to develop complete data records for the EHist temperature analysis is described in Table 2.

Although the plots from Ehist look reasonable, the methodology described above for filling in missing data appears to be flawed. It is stated that missing data were replaced by data from a similar flow year. Presumably a regression exists for flow vs. temperature in one year that can then be applied to flows in the year where water temperature data are missing. However, the water temperature is also a function of air temperature and solar radiation over a number of days preceding the day of water temperature measurement. Data provided by IPC do not indicate which days had synthesized data.

Ehist graphs taken from the Snake River TMDL (Figures 6.1-3, 6.1-4, 6.1-5, 6.1-6) and reproduced in Groves et al. (2007) show that on October 1, 2002, the Ehist Brownlee inflow is 13°C, which is identical to the measured inflow temperature. However, the measured HCC outflow on this date is 18°C. This means that the HCC causes a 5°C increase in water temperature that is in effect until mid-November. This is the thermal shift problem that likely causes a shift in spawning time, incubation survival, or both. If the measured inflow to Brownlee is 13°C on October 1, yet the HCC measured outflow is 18°C, it appears that the HCC causes a significant warming (i.e., 5°C), whereas IPC claims a freedom to warm the river by only 0.5°C.

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Goniea, T.M., M.L. Keefer, T.C. Bjornn, C.A. Peery, D.H. Bennett, and L.C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water. Transactions of the American Fisheries Society 135:408–419.

Abstract.—The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon Oncorhynchus tshawytscha were studied using historical counts at dams and recently collected radiotelemetry data. The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000–2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about 20°C. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2–7°C cooler than the main stem. The proportion of radio-tagged salmon using tributaries increased exponentially as Columbia River temperatures rose within the year, and use was highest in the warmest years. The historical passage data showed significant shifts in fall Chinook salmon run timing distributions concomitant with Columbia River warming and consistent with increasing use of thermal refugia. Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants.

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Progress Report
Effects of Water Temperature Exposure on Spawning Success and Developing Gametes of
Migrating Anadromous Fish - 2004
Study Code: ADS-00-05
by
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Abstract

Examinations into the effects of high sub-lethal water temperature exposures on the reproductive success of migrating anadromous fish were preformed. Investigations included analysis of migration success and the subsequent embryo viability of steelhead and fall Chinook salmon. Radio telemetry methods were used to study migration patterns related to temperature, while viability tests were completed at Lyons Ferry, Nez Perce,

and Dworshak Hatcheries. One hundred steelhead and one hundred Chinook salmon were tagged at Ice Harbor Dam from July 2 to September 30, 2004. We recovered 88 of 200 external and 45 of 108 internal temperature tags released. Included in these, we recovered both the external and internal temperature tags from 15 steelhead and 15 Chinook salmon. Comparisons between these showed that internal body temperature tracked external water temperature closely. Chinook salmon were exposed to temperatures as high as 23.6°C, and had total migration temperature exposures as high as 19.2 degree days above 20°C and 60.0 degree days above 18°C. Steelhead experienced temperatures maximum temperatures of 24°C and had total migration temperature exposures as high as 15.7 degree days above 20°C and 48.8 degree days above 18°C. Migration temperature exposures were highly correlated with release date and the temperature at Ice Harbor Dam at the time of passage. Embryo mortality was tracked for thirty Fall Chinook, and ranged from 1.11% to 19.84%, though one brood exhibited losses over 99% due to soft shell disease. Total embryo mortality was tracked for six steelhead, and ranged from 5.67% to 81.21% with steelhead generally having higher losses than fall Chinook. Embryo mortality data in relation to temperature exposures were analyzed for 13 Chinook salmon. The five fish with the highest temperature exposures above 20°C exhibited five of the six highest embryo mortalities at the eye up stage and the button up stage. A similar, but weaker, relationship was observed when temperature exposures were calculated using an 18°C threshold.

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Technical Report 2006-4

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

ASSOCIATIONS BETWEEN ADULT SALMON AND STEELHEAD BODY TEMPERATURE DURING UPSTREAM MIGRATION AND ESTIMATED ENVIRONMENTAL TEMPERATURES IN LOWER GRANITE RESERVOIR DURING COLD WATER RELEASES FROM DWORSHAK RESERVOIR, 2001-2002

Report for study APS-00-5
under contract DACW68-01-R0008
Task order No. 001
by

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U.S. Army Corps of Engineers
Walla Walla District
2006

Cool-water releases from Dworshak may have conferred a benefit to upstream migrating adults because during warm water temperatures salmonids face an increased risk of disease, decreased swimming performance, increased energetic costs, and decreased gamete production and viability. Colgrove and Wood (1966) reported outbreaks of *Chondrococcus columnaris* in Fraser River sockeye salmon populations in which warm temperatures played a role. Swimming activity used 84% of total energy consumed by upstream migrating sockeye salmon in the Fraser River and areas of difficult passage (Hell's Gate) and elevated water temperatures (21 °C) were energetically costly (Rand and Hinch 1998). Warm temperatures can delay ovulation (Taranger and Hansen 1993) and cause molecular changes in egg development (Jobling et al. 1995; King et al. 2003). DeGaudemar and Beall (1998) found overripening of gametes in Atlantic salmon where egg retention, egg mortality, egg infertility, and egg malformation increased significantly with the number of days past ovulation. Low hatch rate (42% compared to 84% of other stocks) of coho salmon from the Fairview stock in Lake Erie was thought to be due to warm water temperatures affecting ovulation and egg maturation (Flett et al. 1996). Coldwater refuges for fish are becoming a vital element in the survival of salmonids during migration as mean water temperatures increase with changing climate, water- and land-use practices. Changes in the hydrograph and increasing temperatures have caused run timing changes in anadromous fish (Quinn and Adams 1996). Robards and Quinn (2002) found changes in patterns of summer run steelhead in the Columbia River over the past six decades where the bimodal distribution of the early and late run have become closer together and less apparent. With increasing temperatures due to global warming fish habitat will be lost (Keleher and Rahel 1996). Conditions in the Klamath basin for salmonids have deteriorated where it is estimated that temperatures have been increasing by 0.5 °C per decade since the 1960's and the average length of mainstem river with cool summer temperatures has decreased by 8.2 km per decade (Bartholow 2005). Based on one global warming model, Meisner (1990) estimated that increases in temperature in two southern Ontario streams would move thermal barriers causing 30 to 40% habitat loss for brook trout. Several studies have found fish use pools, groundwater discharge, and tributary inflows as thermal refugia (Snucins and Gunn 1995; Biro 1998; Torgersen et al. 1999; Baigun 2003; Baird and Krueger 2003; Goniea et al. 2006; High et al. 2006). Rainbow trout in northeast Oregon streams were found in coldwater patches that were 3 to 8 °C colder than ambient stream temperature from groundwater discharge when temperatures ranged from 18 to 25 °C (Ebersole et al. 2001). Adult and juvenile steelhead in Northern California were found in stratified pools that were 3.5 °C cooler than ambient stream temperatures (Nielsen et al. 1994). In an analogous fashion, adults migrating through the study reach of the Snake River used the cool water created by the Dworshak releases. Interestingly, in the Clearwater River and near the confluence, individuals selected warmer than average water temperatures when mean available model temperatures were below the preferred temperatures reported in the literature (Figure 36). Similarly, Matthews et al. (1994) found rainbow trout and brown trout using stratified pools for thermal refuge in the North Fork of the American River, CA, though fish were not found using the coldest available water.

p. 68.
Overall the results and available literature suggest that migrating adult salmon and steelhead find, use, and benefit from the cooler water that is available in Lower Granite Reservoir during the cold water releases from Dworshak Dam. Consequently, management of Dworshak releases should account for the effects of the releases on adult salmonids as well juveniles. Importantly, there are few potential thermal refuges in the lower Snake River (e.g. cold-water tributaries), highlighting the potential benefit of the Dworshak releases to summer- and fall-run adult salmon and steelhead in the lower Snake River.
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1991.
Behavioral thermoregulation and homing by spring chinook salmon, Oncorhynchus tshawytscha (Walbaum), in the Yakima River.
J. Fish Biology 39:301-312.
Temperature-sensitive radio transmitters were employed to study the patterns of behavioural thermoregulation, habitat preference and movement of 19 adult spring chinook salmon, *Oncurhynchus tshawytscha* (Walbaum), in the Yakima River. During the 4 months prior to spawning, fish maintained an average internal temperature 2.5°C below ambient river temperature. This represented a 12 to 20% decrease in basal metabolic demand or a saving of 17.3 to 29.9 calkg^{-1} h^{-1}. Fish were most commonly associated with islands, pools, and rock out-croppings along stream banks. Homing behaviour appeared to be modified to optimize temperature regimes and energy conservation. As the time of spawning approached, fish left thermal refuges and migrated to spawning grounds upstream and downstream of refuge areas. Although spring chinook salmon residing within cool-water refuges may be capable of mitigating sub-lethal temperature effects, cool-water areas need to be abundant and available to the fish. The availability of suitable thermal refuges and appropriate holding habitat within mainstem rivers may affect long-term population survival.

Monitoring Adult Chinook Salmon, Rainbow Trout, and Steelhead
in Battle Creek, California, from March through October 2001
USFWS Report
Prepared by:
Matt R. Brown
Jess M. Newton

Holding location.—Monitoring results indicate Chinook held in Battle Creek for about 4 months (from early June through early October) prior to spawning. Barrier weir monitoring showed that 75% of unclipped Chinook migrating into Battle Creek had passed the weir by 7 June. Stream surveys indicated that most Chinook did not spawn until early October (see below). Therefore, we considered survey observations made during July, August, and September to be during the holding period for spring Chinook in 2001.

Spawning of potential spring Chinook may have been delayed as 95% of upper Sacramento River spring run are reported to spawn by mid-September (Vogel and Marine, 1991). On Mill Creek, the peak of spawning activity for spring Chinook was estimated to be the last week of September and the first week of October (Harvey Arrison, 2001). In Battle Creek, in previous years with better water temperatures, spring Chinook began spawning by mid-September (RBFWO, unpublished data). In 2001, Chinook holding in the South Fork may have delayed spawning because of unsuitably high water temperatures and low flows. We observed redds in the South Fork being built progressively farther downstream as the spawning season progressed. We observed the first redd in the coolest water immediately below Coleman Diversion Dam (rm 2.5) on 18 September. At this time water temperatures for egg incubation were rated as fair at the dam but very poor (lethal) downstream at Manton Road Bridge (rm 1.7). By the following survey on 3 October, water temperature ratings had upgraded to good at the dam and poor at the bridge and we observed new redds midway between the dam and the bridge. On 16 October, our next survey, water temperatures at the bridge were rated as good for egg incubation and we observed a new redd just downstream of the bridge. Because spawning of potential spring Chinook holding in the South Fork was delayed, their progeny would likely be mis-classified as fall Chinook juveniles according to length criteria commonly used for upper Sacramento River juvenile Chinook. Overall, water temperatures in 2001 were adequate for spring Chinook to successfully produce juveniles but at a reduced number due to temperature-dependant spawner and egg mortality.

Our detection rate of live adult Chinook by stream surveys may have been higher on the South Fork than on other reaches. Based on redd observations, we estimate a total spawning population of 64 and our highest count of live Chinook during monthly stream surveys was 27. Yet, when considering the South Fork only (Reach 3), redd-based estimates and survey counts are much closer; 24 and 17, respectively. As noted previously, differences in flow and geomorphology between reaches may be responsible for differences in detection rate.

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Venditti, David, Catherine Willard, Chris James, Paul Kline, Dan Baker, "Captive Rearing
Program for Salmon River Chinook Salmon", 2002 Annual Report, Project No. 199700100, 73
electronic pages, (BPA Report DOE/BP-00004002-4)

Chilled Water Experiments

A common thread linking previous releases of captive-reared Chinook salmon has been that these fish have consistently spawned several weeks later than their naturally produced counterparts (Hassemer et al. 1999, 2001; Venditti et al. 2002, 2003). In order to address this shortcoming, additional water chilling capacity was added at Eagle in 2001 to assess if water temperature manipulations between the time maturing adults were returned to freshwater and release could be used to advance their spawn timing. While we could find no instances where this has been tested on Chinook salmon, there is a substantial amount of literature describing the effect of temperature on the timing of ovulation in other salmonid species. Elevated holding temperature prior to spawning has been shown to retard the onset of ovulation in rainbow trout O. mykiss (Pankhurst et al. 1996; Pankhurst and Thomas 1998; Davies and Bromage 2002), pink salmon O. gorbuscha (Beacham and Murray 1988), Atlantic salmon (Taranger and Hansen 1993), and Arctic charr Salvelinus alpinus (Gillet 1991; Jobling et al. 1995). However, Henderson (1963) did not observe this relationship in eastern brook trout S. fontinalis.

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Upon reaching spawning areas, adult female Chinook salmon excavate shallow oval shaped depressions in appropriate gravel beds. The depressions, or nests, are known as redds. The general belief is that each female Chinook salmon constructs multiple redds, but observational data suggest one redd per female is most typical (Crisp and Carling 1989; Neilson and Banford 1983). Spawning occurs over several days, during which the female deposits up to five groups, or pockets, of eggs into the redd and then covers them with gravel (Healey 1991).

The specialized life history of salmon restricts flexibility in the duration and timing of the spawning cycle. Spawning salmon are temporally constrained, and regardless of whether conditions are conducive to spawning, they eventually will spawn or die. For example, during unseasonably warm years, salmon may spawn well outside reported preferred, optimal, or suitable water temperature ranges. Therefore, caution should be used in the interpretation and application of water temperature index values derived from observations of spawning Chinook salmon.

2.11 PRE-SPAWN MORTALITY

For purposes of this report, pre-spawn mortality is defined as the proportion of females in the spawning escapement that dies prior to spawning. Typically, pre-spawn mortality estimates are based on carcass survey data relying on direct observation of carcass ovaries. The factors responsible for pre-spawn mortality are poorly understood, although water temperature and disease appear to be significant contributors (Healey 1991; McCullough 1999). Isolating the degree of influence that water temperature and disease have on pre-spawn mortality rates is difficult because water temperature and disease are likely only contributing factors. For example, spatial and temporal variation in ocean conditions can strongly influence the physical condition of migrating salmonids. Migrating salmon in poor condition are affected to a higher degree when exposed to stressful conditions, and are more likely to die prior to spawning. Salmon in poor condition also are more susceptible to disease. Salmon that die unspawned represent an important loss to egg production, and potential decreased escapement in subsequent years. Pre-spawn mortality rates are usually low, but can vary across regions and through time. Shepard (1975) *in* Healey (1991) reported a 19.1 percent pre-spawn mortality estimate for Bear River Chinook salmon, and that 30 of 230 female Chinook salmon in the Babine River died unspawned. In 1965, approximately 25 percent of Chinook salmon in a spawning channel at Priest Rapids, Washington, died prior to spawning, reportedly due to a protozoan infection of the gills (Pauley 1965, as cited *in* Healey 1991). In 1988, DFG reported that in the Trinity River, pre-spawn mortality ranged from a high of 75 percent at the beginning of the spawning season, to a low of 23 percent in the final weeks (Zuspan et al. 1991). The overall female Chinook salmon pre-spawning mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001).

6.6 PRE-SPAWN MORTALITY

Pre-spawn mortality estimates in the lower Feather River from 2000 through 2003 were high when compared to reported estimates from some other systems. Observer bias may account for a small fraction of the high estimates because of the subjective nature of the protocol, however there are likely other contributing factors. In 1988, DFG reported that in the Trinity River pre-spawn mortality ranged from a high of 75 percent at the beginning of the spawn, to a low of 23 percent in the final weeks (Zuspan et al. 1991). The overall female Chinook salmon pre-spawning mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River reportedly ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001). Pre-spawn mortality rates reportedly were 60 percent and 87 percent on Battle Creek in 2002 and 2003, respectively (pers. comm., C. Harvey-Arrison, 2004). In the lower American River, 2003 pre-spawn mortality reportedly was at least 37 percent, and could possibly be higher if partially spawned fish are included (Healey 2004). Pre-spawn morality in the Yuba River, however, was reported to be less than 4 percent in 2003 (pers. comm., S. Theis, 2004). T. Heyne (2004) reported that prespawn mortality rates in tributaries to the San Joaquin River (Tuolumne, Stanislas, and Merced rivers) typically are 5 percent or less. In the Sacramento River, pre-spawn mortality for fall and late-fall-run Chinook salmon were as high as 13 percent in 1996, but was between 3 percent and 8 percent in other years (Snider et al. 1999; Snider et al. 2000). From 2000 through 2003, the pre-spawn mortality estimate in the LFC and HFC averaged approximately 42.5 and 39.7 percent, respectively. The average prespawn mortality rate combining all study years and both reaches was approximately 41.1 percent. For all years and both reaches, 70-100 percent of carcasses inspected in the first four weeks

(September 2 through October 4) were determined to have died prior to spawning. The high estimates during the beginning of the spawning period are of particular concern because federally threatened CV ESU spring-run Chinook salmon may contribute to the initial spawners. The Feather River Hatchery designates all adult salmon arriving up to October 1 as spring-run Chinook salmon, and all fish arriving after October 1 as fall-run Chinook salmon (DFG 1998b). The general belief is that hatchery fish are less genetically fit, and are more susceptible to stressors than are wild fish (Reisenbichler and McIntyre 1977, as cited by McCullough 1999). If this is the case, then it may be that most of the pre-spawn mortality in September in the lower Feather River is attributable to the less resistant hatchery spring-run Chinook salmon. In 2000, 2001, 2002, and 2003, the percentage of inspected carcasses that had an adipose fin clip was approximately 3.1 percent, 4.7 percent, 7.9 percent, and 6.8 percent, respectively. For all years combined, the percentage of inspected carcasses that had an adipose fin clip was 5.6 percent. The percentage of inspected carcasses that had and adipose fin clip in September in 2000, 2001, 2002, and 2003 was approximately 9.2, 12.5, 16.3 percent, and 12.4 percent, respectively. The Feather River Hatchery does not clip all hatchery reared Chinook salmon released into the lower Feather River. The origin of non-clipped salmon is therefore uncertain. Hankin (1982) suggested implementation of several hatchery practices that would allow the discrimination of wild and hatchery fish, most notably for hatcheries to distinctly mark a constant proportion of releases from year to year. Hankin (1982) stated that annual variation in marking proportions rules out later discrimination between returns of hatchery and wild fish. Data from the Feather River Hatchery concerning the proportion of releases distinctly marked were unavailable, but it is unlikely the proportions were constant during those years that would affect the results from this study. Therefore, estimating the proportion of pre-spawn mortality accounted for by naturally spawned spring-run Chinook salmon in the lower Feather River, given available data, is not possible.

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DREDGED MATERIAL MANAGEMENT PLAN
AND ENVIRONMENTAL IMPACT STATEMENT
McNARY RESERVOIR AND LOWER SNAKE RIVER RESERVOIRS
APPENDIX K
Aquatic Resources
prepared by:
U.S. Army Corps of Engineers
Walla Walla District
Walla Walla, WA 99362
with the assistance of:
David H. Bennett, Ph.D.

2.2.4 Temperature and Habitat Use

Temperature appears to regulate the duration of shoreline residence and downriver movement of the fish. Subyearlings appeared to be distributed primarily along the shoreline of the reservoir during their early rearing period in the reservoirs and pelagically oriented once shoreline temperatures exceed 64 to 68 °F (18 to 20 °C). Based on results from 1987, 1990, 1991, and 1992, duration of littoral rearing was longer in the cooler years [*i.e.*, producing higher runoff flows (Curet, 1993)]. Littoral rearing differed from 48 days in 1992 to 84 days in 1991. In 1990 and 1991, when shoreline temperatures remained below 64 °F (18 °C) until mid to late June, subyearlings remained along the shoreline until late June. Peak abundance along the shoreline of the reservoir occurred in late May to early June, 2 weeks later than in 1987 and 1992, which were lower flow years of more rapidly warming shoreline temperatures. As increasing water temperatures result in water too warm for shoreline rearing, subyearlings may move offshore into deeper, faster areas where they rear until commencing their downriver migration.

Connor, W.P., J.G. Sneva, K.F. Tiffan, R.K. Steinhorst, and D. Ross. 2005. Two Alternative Juvenile Life History Types for Fall Chinook Salmon in the Snake River Basin. Transactions of the American Fisheries Society 134:291-304.

Summer flow augmentation provides the highest level of protection for the later-migrating fall Chinook salmon juveniles that are most likely to exhibit the reservoir-type juvenile life history (Connor et al. 2002, 2003c). Given the lack of thermal refuge in the contemporary spawning areas, mortality of these later-migrating fish would be high without summer flow augmentation (range of estimates, 78–87%; Connor et al. 2003c). Therefore, we believe that the reservoir-type juvenile life history is a successful response to large-scale changes in historical habitat that has been enabled or at least enhanced by summer flow augmentation. We also suggest that the decision by managers to save some water in July and August for release in September should further enhance the reservoir-type juvenile life history, provided this decision does not result in temperatures above 20°C in Lower Granite Reservoir during July and August.

Salinger, D.H. and J.J. Anderson. 2006. Effects of Water Temperature and Flow on Adult Salmon Migration Swim Speed and Delay. Trans. Am. Fish. Soc. 135(1):188-199. The effects of temperature and flow on the migration of adult Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* through the Columbia River hydrosystem were determined with a novel technique that fits a broken linear model of swim speed versus temperature and flow by partitioning data into speed ranks. Using the migration times of passive integrated transponder (PIT)–tagged adult Chinook salmon upstream between Bonneville and Lower Granite dams (462 km) over the years 1998–2002, we found that a maximum swim speed of about 1 body length/s occurred at 16.3°C. Speed was less above and below this optimum temperature. For PIT-tagged steelhead, migration speed uniformly decreased with increasing temperature, suggesting that the fish migrated at temperatures above the optimum. Migration delay was also a unimodal function of temperature, the minimum delay occurring around 16–17°C. The broken linear model was compared with seven alternative models of unimodal and monotonic speed versus temperature and flow. The unimodal models fit the data better than the monotonic models (when ranked by the Akaike information criterion), and the broken linear model fit the data best. Flow was insignificant in all of the monotonic models and only marginally significant in the unimodal models. The findings of this study have significance in evaluating the effects of hydrosystem operations and climate change on salmon and steelhead fitness.

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Berejikian, Barry, "Research on Captive Broodstock Programs for Pacific Salmon", 2004-2005 Annual Report, Project No. 199305600, 162 electronic pages, (BPA Report DOE/BP-00017690-1.

survival. Combined with pedigree analyses that estimate individual reproductive success, the ability to quantify spawning frequency and spawn timing of individual fish will improve estimates of natural selection on those characters. For example, adult salmon may experience selective mortality after reaching the spawning grounds and fail to spawn (Quinn and Kinnison 1999). Spawn timing affects emergence timing and may consequently affect offspring growth and survival (Einum and Fleming 2000). Observing or remotely detecting actual spawning events in natural streams would replace less precise surrogate estimates of spawn timing such as migration timing (Seamons et al. 2004).

There is growing evidence that rearing temperatures can alter the timing of spawning as well as gamete quality (e.g. Taranger and Hansen 1993; Pankhurst et al. 1996; Pankhurst and Thomas 1998; Taranger et al. 1999; King and Pankhurst 1999; Davies and Bromage 2002). Preliminary studies with Snake River spring Chinook salmon have shown that chilling fresh water during the final months preceding spawning achieves a slight advancement of spawning time (Venditti et al. 2003). Extensive studies on Atlantic salmon have shown advancement of spawn timing and improvements in egg quality with reduced water temperatures (e.g. King et al. 2003). Given that rearing temperatures for captive Snake River spring Chinook salmon in the captive broodstock programs may be several degrees higher than they would experience in the ocean and river during the upstream migration, it is plausible that rearing temperatures may underlie some of the reproductive problems. Therefore, an experiment is being conducted to examine the effects of reducing rearing temperature for 12 months in seawater and 2 to 4 months in fresh water on reproductive performance of spring Chinook salmon. Since there may be stock differences in response to temperature, two stocks of fish are being used in this experiment.

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Transactions of the American Fisheries Society 135:408–419, 2006

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Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures

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LOWELL C. STUEHRENBERG

Abstract.—The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon *Oncorhynchus tshawytscha* were studied using historical counts at dams and recently collected radiotelemetry data. The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000–2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about 20°C. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2–7°C cooler than the main stem. The proportion of radio-tagged salmon using tributaries increased exponentially as Columbia River temperatures rose within the year, and use was highest in the warmest years. The historical passage data showed significant shifts in fall Chinook salmon run timing distributions concomitant with Columbia River warming and consistent with increasing use of thermal refugia. Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants.

Richard S. Brown and David R. Geist. 2002. Determination of Swimming Speeds and Energetic Demands of Upriver Migrating Fall Chinook Salmon (*Oncorhynchus tshawytscha*) in the Klickitat River, Washington. PNNL-13975. Submitted to Bonneville Power Administration. Project Number 22063, Contract 42663A.

The study also examined energy costs and swimming speeds for fish released above Lyle Falls as they migrated to upstream spawning areas. This journey averaged 15.93 days to travel a mean maximum of 37.6 km upstream at a total energy cost of approx 3,971 kcals (34% anaerobic and 66% aerobic) for a sample of five fish. A bioenergetics example was run, which estimated that fall chinook salmon would expend an estimated 1,208 kcal to pass from the mouth of the Columbia River to Bonneville Dam and874 kcals to pass Bonneville Dam and pool and the three falls on the Lower Klickitat River, plus an additional 2,770 kcals above the falls to reach the spawning grounds, leaving them with approximately 18% (1,089 kcals) of their original energy reserves for spawning. Results of the bioenergetics example suggest that a delay of 9 to 11 days along the lower Klickitat River may deplete their remaining energy reserves (at a rate of about 105 kcal d^{-1}) resulting in death before spawning would occur.

Note: if a 9-11 day migration delay risks death to Klickitat fall Chinook, the extensive delays and fallback rates on the Snake River are likely to cause more serious mortalities, bioenergetic stress, and inability to delay spawning time to accommodate the 3-week shift in temperature peaks.

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- Richards, M. 1959. Snake river fall Chinook spawning ground survey, 1959. Idaho Department of Fish and Game.

SNAKE RIVER FALL CHINOOK SPAWNING GROUND SURVEY, 1959

DISEASE

During the 1958 survey, a relatively large number of fish was observed to have lesions typical of columnaris. This condition was again observed early in the 1959 survey and, during the remainder of the survey, fish bearing lesions typical of columnaris, in sample, were recorded. The sample was limited to carcasses fresh enough that accurate determinations could be made and to carcasses checked by a qualified observer.[1] A sample of 74 dead fish showed the typical lesions to be present in 77.0 per cent of the fish sampled. Of 53 dead fish sampled and classified as to size and sex, 100 per cent of the adult males and of the females and 63.3 per cent of the jacks had lesions typical of columnaris.

Table 1.--Fall chinook salmon counts, by month, Brownlee Dam, 1957 and Oxbow Dam, 1958 and 1959

Month	1957	1958	1959
August	63	1	27
September	3,517	4,732	6,043
October	10,686	9,285	5,694
November	643	60	66
December	43	0	0
Totals	14,952	14,078	11,830

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Idaho Department of Fish and Game. 1960.

SNAKE RIVER FALL CHINOOK SPAWNING GROUND SURVEY 1960

A sample of 37 dead fish showed typical gill lesions to be present in 62.2 per cent of the fish samples. Number and per cent of sampled fish with gill lesions typical of columnaris, by sex and by size classification for males, are shown in Table 7.

A total of three fish were found with characteristic symptoms of furunculosis.

Based on the spawning ground sample, jacks (assumed two-year old fish) comprised 15.1 per cent of the 1960 run. Because of fluctuating sizes of

Table 9.--Comparison of size of parent run and calculated number of returning two-year old fish, Snake River fall chinook, 1957-1960.

Year	Parent run redd count	Year	Fish counted at Brownlee-Oxbow Dams	Spawning ground jack percentage	Calculated no. of returning two-year old fish
1955	513	1957	14,952	31.9	4,770
1956	268	1958	14,078*	13.7	1,929
1957	2,656	1959	11,830	50.3	5,950
1958	993	1960	5,131	15.1	775

Table 1.--Fall chinook salmon counts, by month, Oxbow Dam, 1960

Month	1960
August	56
September	3,266
October	1,462
November	125
December	2
Total	4,911*

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A THREE YEAR STUDY
OF FALL CHINOOK SALMON SPAWNING AREAS
IN SNAKE RIVER ABOVE HELLS CANYON DAM SITE

by

Paul D. Zimmer
Fishery Management Biologist

July 1950

Report
of
FISH AND WILDLIFE SERVICE
Region 1
Portland, Oregon
Leo L. Laythe, Regional Director

p. 10.

14. Boat observations conducted in October were very unsatisfactory for several reasons. The nearness of the observers to the water, which restricted their vision to about ten feet on either side of the boat, the rapid speed of travel over the riffle areas, and the strong winds and overcast sky all contributed to make an accurate count of nests impossible. In contrast to this it was found that aerial observations were not seriously affected by the strong winds, overcast sky or any of the other factors that had so influenced the boat survey. Because of the exceptionally clear water which prevailed throughout the entire period of aerial observations all nests were clearly visible to the aerial observer at the time of the November count. It was considered that the total nests counted on November 6 represented all of the spawning which had previously occurred. [illegible]

- p. 11

Table 3. SUMMARY OF SPAWNING-BED OBSERVATIONS OF 1947

Date	Section of River Examined	Visibility in water	Number of Nests observed 1/	Method of Counting Nests	Hours Spent in Observation
Oct. 3	Vicinity of Murphy Bridge	Poor	3	From bank	6
Oct. 15	Swan Falls to Murphy Bridge	Poor	73	Boat	8
Oct. 17	Murphy Bridge to 10 miles above Marsing Bridge	Poor	0	Boat	8
Oct. 17	Swan Falls to Marsing Bridge	Excellent	1390	Plane	3
Oct. 17	Marsing Bridge to Weiser	Excellent	0	Plane	3
Nov. 6	Swan Falls to Murphy Bridge	Excellent	3311	Plane	3
Nov. 6	Murphy Bridge to Marsing Bridge	Excellent	483	Plane	2
Nov. 6	Marsing Bridge to Weiser	Excellent	10	Plane	2

p. 17.

20. Shortly after October 18, 1949, the river cleared up and the nests made from then until November 22, the date of the second survey, were free of silt and readily distinguishable from those made earlier. On the date of the latter survey only those nests were counted which were clearly defined and considered to have been made after October 18. Total nests counted in 1949 was 348, Table 5.

p. 18.

Tab;e 5. SUMMARY OF SPAWNING-BED OBSERVATIONS OF 1949

Date	Section of River Examined	Visibility in water	Number of Nests observed 1/	Method of Counting Nests	Hours Spent in Observation
Oct. 18	Swan Falls to Murphy Bridge	Fair	148	Plane	2
Oct. 18	Murphy Bridge to Marsing	Fair	13	Plane	1
Oct. 18	Marsing to Weiser	Fair	0	Plane	3
Nov. 22	Swan Falls to Murphy Bridge	Good	144	Plane	2.5
Nov. 22	Murphy Bridge to Marsing	Good	38	Plane	2
Nov. 22	Marsing to Weiser	Good	5	Plane	3

SUMMARY

27. Excellent spawning and rearing conditions for fall chinook salmon are present in the section of Snake River between upper end of Hells Canyon and Swan Falls, Idaho.

28. It appears from the information available that the spawning period of fall chinook salmon in the Snake River above Hells Canyon Dam site starts in late September or early October and is completed by early December.

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Olson, P.A.,
R.E. Nakatani, and T. Meekin.
1970.
Effects of thermal increments on eggs and young of Columbia River fall chinook. Battelle Memorial Inst., Pac. Northwest Lab. Rep. BNWL-1538, Richland, WA. 23 p. + 8 tables and 25 figures [QL 639.25, .E4441 1970]

Series III (November 23 Spawning)

The apparent tolerance of this series to high temperature increments was greater than the preceding two because of the rapid decrease of Columbia River temperatures during the winter. Increments as high as 10.8 °F resulted in low total mortalities of 10.3 percent, well within the range of normal hatchery production. Excessive mortalities were evident only at the greatest increment tested (12.8 °F). An addition of 2 °F over the 10.8 °F increment of Lot 6 resulted in a drastic mortality increase. Total mortalities revealed an erratic pattern that was inconsistent with increasing temperature increments up to 10.8 °F. Statistical tests reflected the erratic results since mortalties of Lot 5 (+8.8 °F) were not significantly greater than Lot 1, whereas losses in the other lots (Lots 2,3 and 4) showed significantly greater mortalities. Although temperature levels in these lots resulted in generally low mortalities even with thermal increments as great as 10.8 °F, the erratic pattern showed no consistent trend over this temperature range.

p. 17.

Because of falling river temperatures after the start of the initial experiment, successively later series tolerated greater thermal increments. Temperatures 7.0 °F in excess of base river temperatures resulted in excessive mortalities in Series I (spawned Oct. 30) and 12.0 °F resulted in total mortality. However, a 12.5 °F increment above river temperatures in Series IV (spawned Dec. 8) produced a mortality of only 12.4%, well within the range of normal hatchery production. Temperature increments averaging 2.9 to 2.8 °F for Series I and II (spawned Oct. 30 and Nov. 14) and 6.5 °F for Series IV (spawned Dec. 8) did not significantly increase either total or fish mortalities over the coldest lots experiencing normal base river temperatures. Experimental temperatures that produced no significant increase in the mortality of these three series are shown in Figure 25. Data from Series III (spawned No. 23) were not used because of erratic and hard-to-relate mortality-temperature correlations.

p. 18.

egg mortalities also experienced greater losses during the fry stage. Under cooler, but still adverse temperature treatments, egg and fry mortalities were not obviously greater, but increased losses occurred primarily during the critical transition period at commencement of active feeding. Once the

Hanrahan, T.P.,
D.R. Geist, E.V. Arntzen, and C.S. Abernethy.
2004.
Effects of Hyporheic Exchange Flows on Egg Pocket Water Temperature in Snake River Fall Chinook Salmon Spawning Areas.
PNNL-14850, Pacific Northwest National Laboratory, Richland, WA.

p. 1.1.

Prior to the construction of the Hells Canyon Complex of dams on the Snake River, fall Chinook salmon (*Oncorhynchus tshawytscha*) migrated to their primary production areas between Marsing, Idaho, and Swan Falls, Idaho, approximately 300 river kilometers (rkm) upstream of the present spawning areas in Hells Canyon (Dauble et al. 2003). Current fall Chinook salmon spawning areas in the Snake River occur downstream of Hells Canyon Dam, which now is the upstream terminus for anadromous fish migration in the Snake River Basin. The historic spawning areas contained different water temperature regimes than the present spawning areas. Consequently, water temperatures during the egg incubation period (~December–May) may have been relatively warmer in the historic production areas than in the current spawning areas. This difference in temperature regimes may be the reason that fall Chinook salmon from current production areas in the Hells Canyon Reach arrive at the Lower Granite Dam section of the Snake River 1 to 4 weeks later than they did before development of the Hells Canyon Complex and the four lower Snake River projects operated by the U.S. Army Corps of Engineers (NMFS 2000a; Connor et al. 2001).

The shift toward later emergence and migration requires smolts to migrate through downstream reservoirs during mid- to late-summer when environmental conditions are unfavorable for survival (Connor et al. 2001). The differential survival among cohorts of wild Snake River subyearling juvenile Chinook can be traced back to emergence timing, with earlier emerging fish migrating earlier through Lower Granite Reservoir under conditions of higher flows and cooler water temperatures than later emerging fish (Connor 1999). Later migration puts juvenile migrants in reservoirs during periods when water temperatures approach Chinook salmon's thermal tolerance (NMFS 2000a). The delay also places late arriving fall Chinook in unsuitable reservoir environments, and may increase their susceptibility to predation.

p. 1.2

Recent research in the Hells Canyon Reach of the Snake River indicates that warm hyporheic water upwells into fall Chinook salmon spawning areas (Geist et al. 1999; Arntzen et al. 2001). The magnitude and duration of hyporheic water upwelling into these fall Chinook salmon spawning areas is inversely related to discharge from Hells Canyon Dam. During the October – December period when flows are held stable to allow fall Chinook salmon to spawn, the water temperature of the hyporheic zone is up to 2°C warmer than the river water, and hydraulic gradients suggest upwelling potential into the river channel. Under current operations by Idaho Power Company (IPC) and beginning in mid-October, the discharge from Hells Canyon Dam is lowered and daily fluctuations are minimized to benefit spawning fall Chinook salmon within the mainstem Snake River. As discharge decreases, the magnitude of hyporheic upwelling potential at these areas increases (Geist et al. 1999). The period of low, stable discharge from Hells Canyon Dam terminates at the end of the fall Chinook spawning period and the discharge pattern reverts to those of prior operations (i.e., large, variable discharge caused by power-peaking operations). By early December (i.e., early in the egg incubation period), the upwelling hyporheic water was 2°C warmer than the river water (Geist et al. 1999). It is likely that as incubation progresses into February and March, the difference in temperature between the hyporheic zone and the river becomes greater than 2°C. However, there are currently no empirical data quantifying the surface water–ground water interactions occurring during the fall Chinook salmon incubation and emergence periods within Hells Canyon, and thus no way to substantiate this hypothesis.

p. 2.6

L is the distance (cm) from the top of the piezometer screen to the riverbed surface. The VHG represents a potential for upwelling from the hyporheic zone (positive VHG) or downwelling into the hyporheic zone (negative VHG). Analyses of hydraulic gradients between the river and riverbed were primarily based on dh values. The dh values were used so that hydraulic gradients could be evaluated relative to the uncertainty error of the instruments (±1.4 cm), which does not vary over the range of depths for which they were used in this study. Differences in mean dh among sites and time period (spawning, early

p. 3.7

Each of the lower, middle, and upper segments of the study area included sites exhibiting both upwelling and downwelling potential. Sites within the lower segment had a mean dh ranging from -0.1 cm (±0.7 cm SD) to 1.6 cm (±0.4 cm SD) during the spawning period, from -0.9 cm (±0.6 cm SD) to 1.6 cm (±0.3 cm SD) during the early incubation period, and from -0.6 cm (±0.7 cm SD) to 3.2 cm (±0.9 cm SD) during the late incubation period (Figures 6 and 7). Within the middle segment, the range of mean dh among sites was much larger, ranging from -1.0 cm (±0.4 cm SD) to 4.7 cm (±0.5 cm SD) during the spawning period, from -1.5 cm (±0.7 cm SD) to 4.6 cm (±0.4 cm SD) during the early incubation period, and from -1.0 cm (±0.5 cm SD) to 4.7 cm (±0.8 cm SD) during the late incubation period (Figures 6 and 7). Sites within the upper segment also had a large range of mean dh, ranging from 0.3 cm (±0.7 cm SD) to 3.4 cm (±0.6 cm SD) during the spawning period, from 0.2 cm (±0.6 cm SD) to 3.7 cm (±0.6 cm SD) during the early incubation period, and from -0.3 cm (±1.6 cm SD) to 3.1 cm (±1.2 cm SD) during the late incubation period (Figures 6 and 7). Tests for differences in mean dh among all sites resulted in indications of significant differences for nearly all sites in all time periods (Tables 5 and 6). However, many of the differences in mean dh were less than 1.5 cm, which is approaching the pressure transducer uncertainty error of ±1.4 cm.

p. 3.11

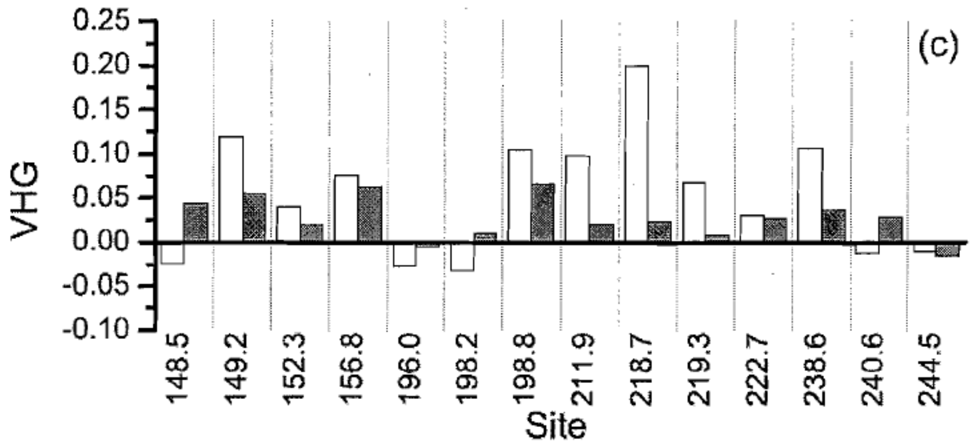


Figure 8. Mean vertical hydraulic gradient (VHG) between the river and shallow hyporheic zone (□), and between the river and deep hyporheic zone (■) during (a) the spawning period (20 October 2002 – 2 December 2002), (b) the incubation period with low, stable discharge (19 November 2002 – 7 January 2003), and (c) the incubation period with variable discharge (8 January – 2 March 2003). Positive values indicate upwelling potential while negative values indicate downwelling potential.

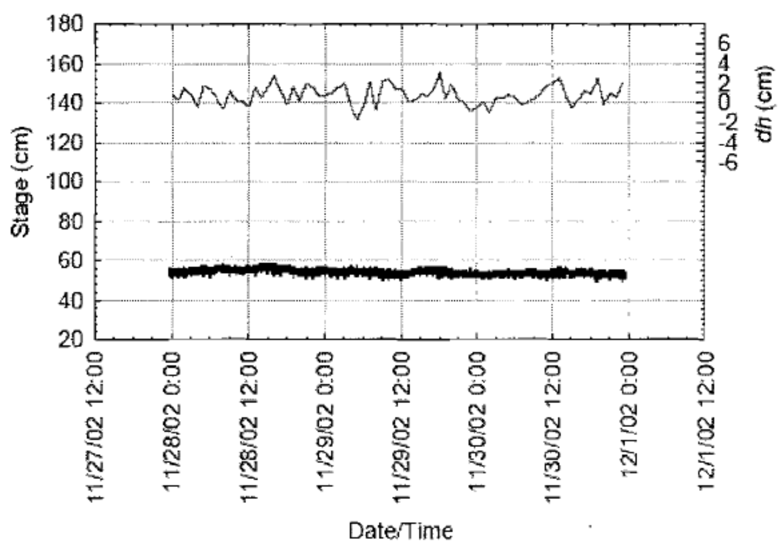
p. 3.37

Table 9. Summary of mean (± standard deviation) water temperature (°C) in the river (R), egg pocket (EP), shallow hyporheic zone (SH), and deep hyporheic zone (DH) at each site during the early spawning period (20 October 2002–18 November 2002), the mid-to-late spawning period and early incubation period (19 November–2 December 2002), the early incubation period with low, stable discharge (19 November 2002–7 January 2003), and the incubation period with variable discharge (8 January–2 March 2003). The overlapping time periods are provided for the separate analyses of fall Chinook salmon life stages (i.e., spawning and incubation).

3.37

	Early spawning period		
Site	R	SH	DH
L†			
148.5	10.0 (1.7)	10.3 (1.6)	10.6 (1.5)
149.2	9.9 (1.7)	10.2 (1.6)	10.9 (1.5)
152.3	10.0 (1.7)	10.9 (1.5)	11.4 (1.5)
156.8	10.1 (1.7)	10.4 (1.6)	10.8 (1.5)
M†			
196.0	12.5 (1.6)	12.5 (1.5)	12.6 (1.6)
198.2	12.6 (1.5)	12.6 (1.5)	13.0 (1.5)
198.8	12.5 (1.5)	12.7 (1.5)	12.9 (1.4)
211.9	12.5 (1.6)	13.0 (1.6)	13.5 (1.6)
218.7	12.7 (1.6)	13.2 (1.4)	13.4 (1.4)
219.3	12.6 (1.6)	13.0 (1.6)	13.0 (1.6)
222.7	12.8 (1.6)	13.3 (1.4)	13.4 (1.4)
U†			
238.6	12.8 (1.6)	13.1 (1.4)	13.6 (1.3)
240.6	12.8 (1.6)	13.1 (1.6)	13.3 (1.6)
244.5	12.8 (1.6)	12.8 (1.6)	13.0 (1.6)

p. A-14



Appendix Figure 14. Time-series summary of water temperature (top panel) and river stage (bottom panel) at site 244.5 during a period of low, stable river discharge (November 28 – 30, 2002). Average hourly water temperature is shown for the river (+), egg pocket (O), shallow hyporheic (●) and deep hyporheic (▲) zones. Average hourly stage (depth) is shown for the river (+), and shallow hyporheic zone (●). The difference between these two water depths (hyporheic minus river) is plotted on the Y-right axis as *dh* (—), with positive values indicating upwelling potential.

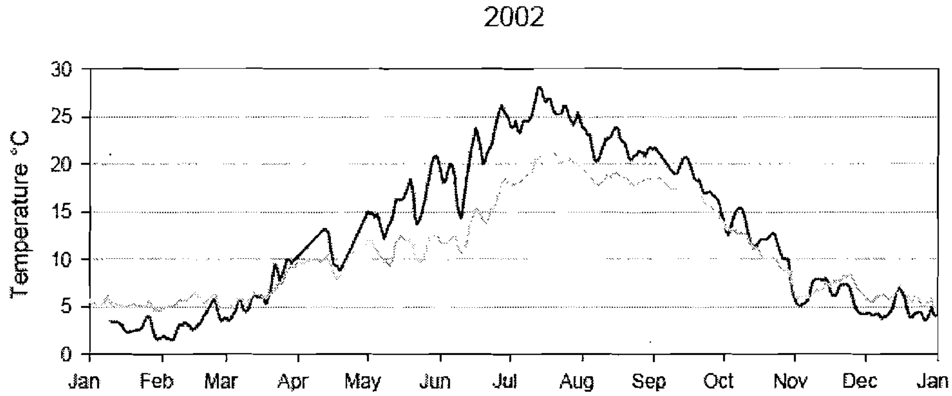


Figure 6.1-3. Measured and estimated historic (EHist) temperatures in degree Centigrade (°C) in the Snake River inflow to Brownlee Reservoir for medium (1995), high (1997) and low (2002) water years.

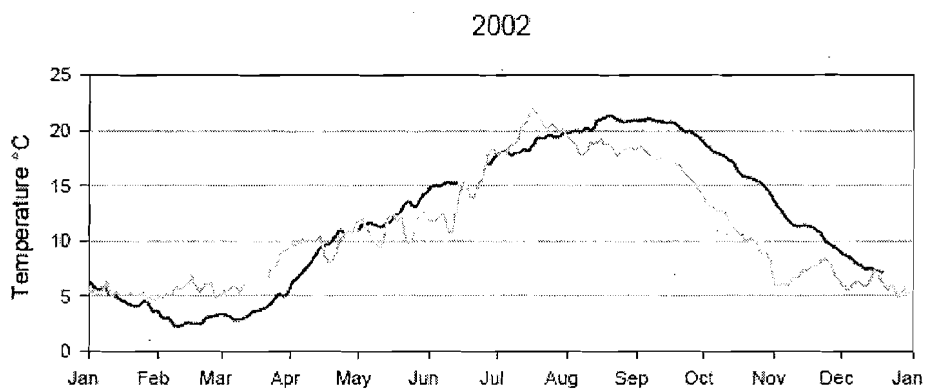


Figure 6.1-4. Measured Hells Canyon Complex (HCC) outflow temperatures in degree Centigrade (°C) and estimated historic (EHist) inflow temperatures in the Snake River for medium (1995), high (1997) and low (2002) water years.

2002

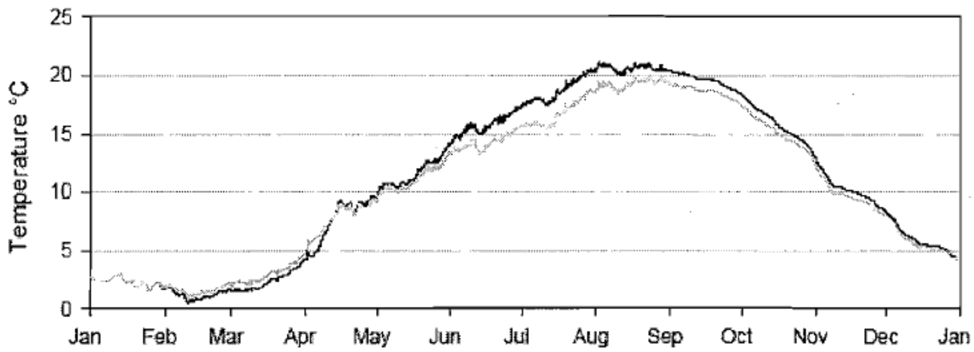


Figure 6.1-6. Modeled Hells Canyon Complex outflow temperatures in degree Centigrade (°C) using current (baseline) and estimated historic (EHist) temperatures inflow to Brownlee Reservoir for low water years (1992, 1994 and 2002).

p. 385.

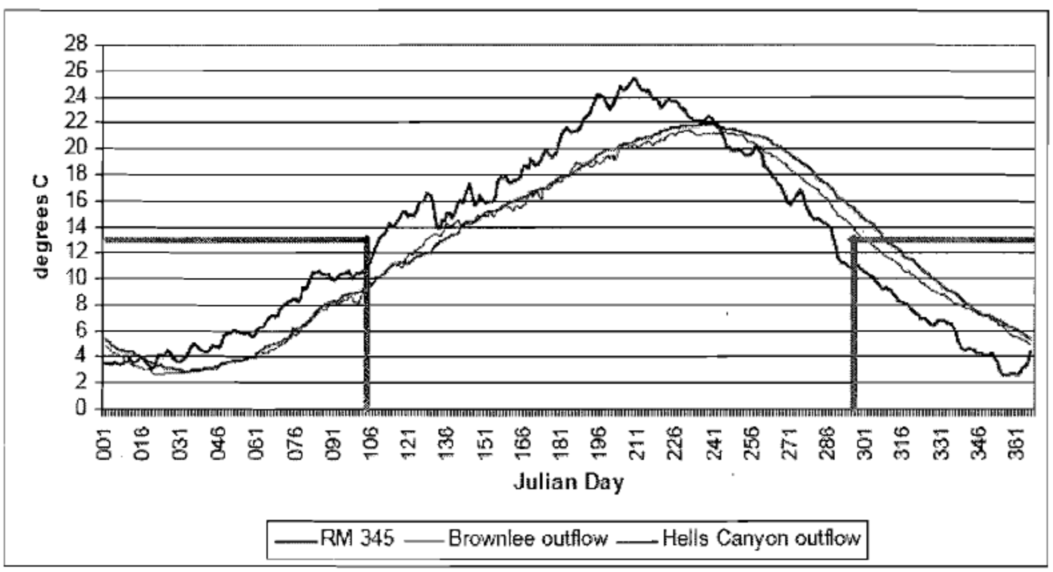


Figure 3.6.4 a. Post-construction daily mean water temperature data for the Snake River above and below the Hells Canyon Complex dams. (Salmonid spawning periods (boxes) for the Snake River below Hells Canyon Dam are displayed specific to fall chinook in this reach.)

Hanrahan et al. (2004)

p. 1.1

current spawning areas. This difference in temperature regimes may be the reason that fall Chinook salmon from current production areas in the Hells Canyon Reach arrive at the Lower Granite Dam section of the Snake River 1 to 4 weeks later than they did before development of the Hells Canyon Complex and the four lower Snake River projects operated by the U.S. Army Corps of Engineers (NMFS 2000a; Connor et al. 2001).

Geist, D. and A.Currie. 2006. Evaluation of Salmon Spawning below the Four Lowermost Columbia River Dams", 2004-2005 Annual Report, Project No. 199900301, 59 electronic pages,(BPA Report DOE/BP-00000652-32).

Examination of temperature data reveals several important patterns. Piezometer sites differ in the direction of vertical flow between surface and subsurface water. Bed temperatures in upwelling areas are more stable during salmon spawning and incubation than in downwelling areas. Bed temperatures in downwelling areas generally reflect river temperatures. Chum and fall Chinook salmon spawning is spatially segregated, with chum salmon in upwelling areas and fall Chinook salmon in downwelling areas. Although these general patterns remain similar among years, differences also exist that are dependent on interannual flow characteristics.

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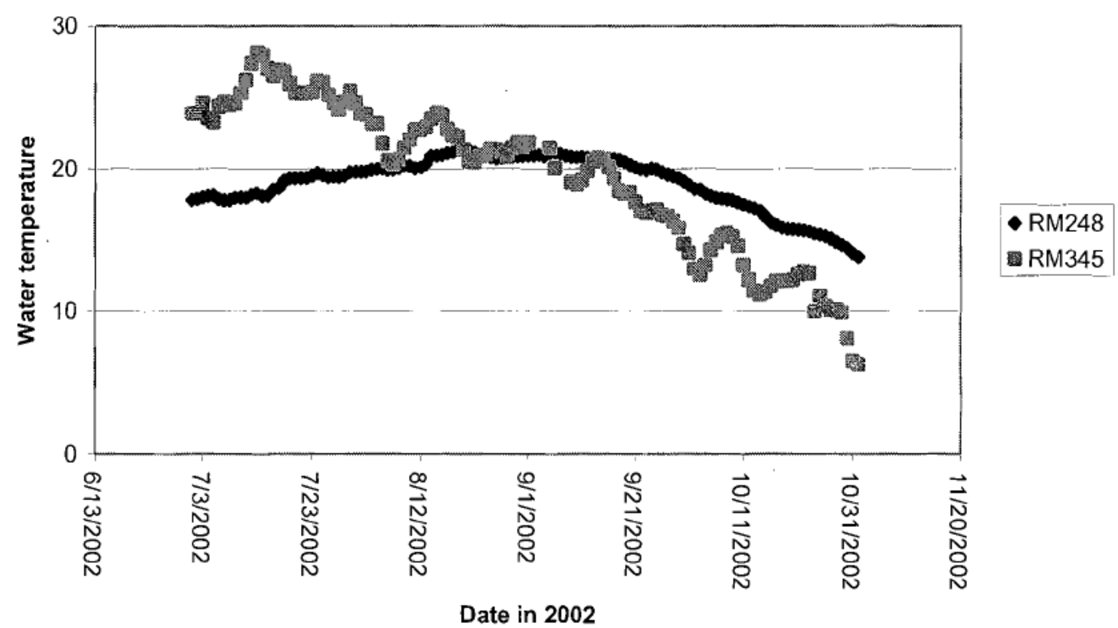
Plot below is from data sent to ODEQ by IPC for measured temperatures at RM248 and RM345 in 2002. Graph produced by McCullough (CRITFC) from IPC data.



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[Idaho Power Company (IPC). 2007. Section 401 water quality certification application. Hells Canyon Complex. FERC No. 1971. Submitted to Idaho Department of Environmental Quality and Oregon Department of Environmental Quality. January 31, 2007.]

The FERC project boundary for the HCC extends from just above Porter Island [River Mile (RM) 343], within Malheur County in the State of Oregon, about five miles northwest of Weiser, Idaho, to Hells Canyon Dam (RM 247.6) in Wallowa County, Oregon (Figure 1.1-1). (IPC 2007).

Measurements at Brownlee Dam showed unmixed conditions at the bridge (113%–138%), mixed conditions about four miles downstream of the dam (135%) (river mile 280.4)....

272.8 Oxbow Dam

(RM 345.6) and outflow from Hells Canyon Dam (RM 247.6).

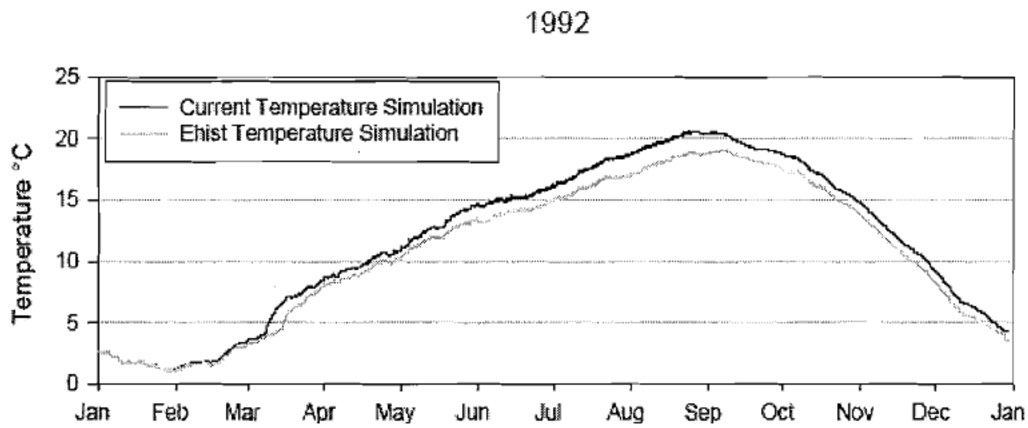

Figure 6.1-6. Modeled Hells Canyon Complex outflow temperatures in degree Centigrade (°C) using current (baseline) and estimated historic (EHist) temperatures inflow to Brownlee Reservoir for low water years (1992, 1994 and 2002).

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Hydro Projects upstream of HCC—data from
www.nww.usace.army.mil/html/offices/pa/WRD-ID99.pdf
http://www.nwcouncil.org/maps/power/Default.htm

Lucky Peak (101mw Hydro)
Owner: Boise Proj. Board of Control, started 1988

Swan Falls (25mw Hydro)
Owner: Idaho Power Co., started **1901**. Acquired by IPC in 1916.
Reservoir holds 7,425 acre feet; at RM457

C.J. Strike (82mw Hydro)
Owner: Idaho Power Co., started **1952**
Reservoir holds 247,000 acre-feet; at RM494

Bliss (75mw Hydro)
Owner: Idaho Power Co., started **1949**
Reservoir holds 8,415 acre-feet; at RM560

Lower Salmon Falls (60mw Hydro)
Owner: Idaho Power Co., started **1910**, rebuilt 1949.
Reservoir holds 10,900 acre-feet.

Upper Salmon Dam
Owner: Idaho Power Co.
Reservoir holds 600 acre-feet; at RM 580

Lower and Upper Malad Dams
Owner: Idaho Power Co., built **1911**
Upper Malad project on Malad River at RM 2.1; Lower Malad project on Snake River at RM 571.2

Twin Falls A & B (52mw Hydro)
Owner: Idaho Power Co., started **1935**; updated in 1995
Reservoir holds 955 acre-feet

Milner A (58mw Hydro)
Owner: Idaho Power Co., started 1992; in operation as an irrigation project since **1905**.
Reservoir holds 39,000 acre-feet.

American Falls (92mw Hydro)
Owner: Idaho Power Co. financed, operated by USBOR
Original dam was an earthen dam built in **1927**; reconstructed between 1976-1978.
Reservoir holds 1,671,300 acre-feet; at RM 715.

Thousand Springs Dam
Owner: Idaho Power Co.; built **1912**, updated 1921.
8.8 mw;

Clear Lake Power Plant
Owner: Idaho Power Co.; build **1937**
at RM 593

Shoshone Falls Dam
Owner: Idaho Power Co.; build **1907**, rebuilt 1921.
Reservoir holds 1,500 acre feet; at RM 615

Palisades (118mw Hydro)
Owner: U.S. Bureau of Reclamation, started **1957**

Minidoka (27mw Hydro)
Owner: U.S. Bureau of Reclamation, started **1906**
Capacity at Elev: 4245.0 ft, Usable storage of 210,000 acre-feet
at RM675.

- -- -- -- --

Upstream migration rates of radio-tagged adult Chinook salmon in riverine habitats of the Columbia River basin

M. L. KEEFER*†, C. A. PEERY*, M. A. JEPSON* AND L. C. STUEHRENBERG‡

Journal of Fish Biology (2004) **65**, 1126–1141

Oncorhynchus gorbuscha (Walbaum) (Smoker *et al.*, 1998) salmon. Strategies for optimal adult arrival range from very early migration and long freshwater residence (*e.g.* some steelhead and Atlantic salmon stocks) to rapid migration by mature fishes just prior to spawning [*e.g.* some Columbia River autumn (fall) Chinook salmon]. With either strategy, arrival at the most suitable time can lead to reproductive advantages for individual fish, such as selection of prime spawning sites and safe holding positions, and improved overall population fitness (Hawkins & Smith, 1986; Smoker *et al.*, 1998). Alternatively, fishes entering the river relatively late within each run face reduced mating opportunities if they reach the spawning grounds after most spawning activity has occurred. These fishes may swim more rapidly, irrespective of discharge or temperature to reach spawning grounds before the window of opportunity for spawning closes. The observed seasonal increase in spring–summer Chinook salmon migration rates may incorporate a variety of these mechanisms, though the contribution of each remains unknown.

consequences for overall survival. Longer adult exposure to elevated temperatures may result in higher prespawn mortality (Gilhousen, 1990; Dauble & Mueller, 2000; C.B. Schreck, J.C. Snelling, R.E. Ewing, C.S. Bradford, L.E. Davis & C.H. Slater, pers. comm.) or reduced gonadal development or egg viability (Kinnison *et al.*, 2001). Further research on the relationships between river discharge and temperature, migration rates, spawning success and juvenile recruitment are recommended for managers interested in protection and enhancement of extant stocks.

- - -- -- -

Late-season mortality during migration of radio-tagged adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River

George P. Naughton, Christopher C. Caudill, Matthew L. Keefer, Theodore C. Bjornn, Lowell C. Stuehrenberg, and Christopher A. Peery

Abstract: We radio-tagged 577 adult sockeye salmon (*Oncorhynchus nerka*) returning to the Columbia River in 1997 to determine how migration behaviors were related to migration success in an altered river system. The probability of successful migration declined dramatically for late-entry individuals, concomitant with declines in discharge and the onset of stressful temperatures. Long dam passage times were not related to unsuccessful migration at most dams. However, when migration histories were analyzed across multiple dams or reservoirs, relatively slow migration was significantly associated with unsuccessful migration, suggesting potential cumulative effects. Median passage times at dams were rapid (7.9–33.4 h), although 0.2%–8% of salmon took more than 5 days to pass. Reservoir passage was also rapid, averaging 36.8–61.3 km·day^{-1}, and appeared to compensate for slowed migration at dams. Rates observed in the unimpounded Hanford Reach suggest that total predam migration rates may have been similar to current rates. Overall, our results suggest that cumulative effects may be more important than negative effects of passage at single dams and that hydrosystem alteration of temperature regimes in the migration corridor may have an important indirect negative impact on adults.

Can. J. Fish. Aquat. Sci. 62: 30–47 (2005)

Nonetheless, temperature was probably the primary factor affecting migration success. Elevated water temperatures during upstream migration have been linked to higher in-river and prespawning mortality of sockeye salmon in the Columbia Basin (Major and Mighell 1967) and the Fraser River (Gilhousen 1990; Macdonald et al. 2000; Cooke et al. 2004). Adult exposure to elevated temperatures can increase susceptibility to disease and compromise reproductive performance (Coutant 1999; Torgersen et al. 1999) through increased metabolic demands (Rand and Hinch 1998), reduced allocation to gonadal development (Kinnison et al. 2001), and reduced egg viability (Berman and Quinn 1991). Extended exposure of adult salmonids to water temperatures >18 °C may increase the risk of prespawning mortality (mortality after adults have reached spawning tributaries; Becker and Fujihara 1978; Gilhousen 1990), and temperatures above 24 °C are lethal (Servizi and Jensen 1977). Cooke et al. (2004) identified several mechanisms that may have contributed to the dramatic in-river and prespawn mortality observed in late-run sockeye salmon in the Fraser River since 1995. While underlying causes of mortality are still unclear in the Fraser River, it is likely that temperature plays a direct or indirect role because the high mortality has been observed in a portion of the run entering the river more than 6 weeks earlier in the season than the historical pattern, shifting migration to a period of warmer water temperatures in August (Cooke et al. 2004). In our study, the precipitous drop in migration success occurred for sockeye salmon tagged after the second week of July as temperatures at Bonneville Dam and elsewhere in the drainage exceeded 20 °C.

the late period did not die immediately after release. Finally, we estimated survival for sockeye salmon migrating during these two periods using dam count data from Bonneville and Rock Island dams and assuming a 16-day passage time between these dams (the mean migration time observed for sockeye salmon tagged on 4–16 July). Although these estimates have several potential sources of error, a large decline in survival was also observed in the dam count sample, with estimated migration success dropping from 94.2% to 56.3% later in the summer. Taken together, ancillary evidence sug-

Several mechanisms may have contributed to the observed relationships among migration success, speed, and season. First, the relationship between migration success and speed could be direct, where slowed migration caused by dams resulted in the expenditure of energy that slowed migration at upstream projects and subsequently lowered the probability of successful migration. Alternatively, slow migration may have resulted from poor initial physiological condition leading to slowed migration, increased thermal exposure, and subsequent low probability of migration success. These two

Notably, the seasonal pattern of mortality may have been related to both factors. It is plausible that late-entry fish were in relatively poor initial physiological state, perhaps having delayed entry to continue ocean feeding, and this subsequently led to poor initial condition, slow migration rates, increased thermal exposure, and low migration success. Clearly, understanding the relationship between initial condition and migration success is important in a management context because the relative importance of each mechanism will determine the effectiveness of management actions aimed at improving passage conditions at dams — efforts to improve passage at dams will provide little benefit if migration success is primarily related to fish condition at river entry.

Regardless of mechanism, the observed pattern of seasonal mortality suggests the potential for current selection on run timing. The upstream migration of anadromous salmonids is an energetically demanding part of the life cycle and its initiation is largely governed by the interactions of water temperature, flow regime, and other factors that influence maturation (Gilhousen 1990; Hodgson and Quinn 2002). Substantial variation exists in the timing of spawning migrations of North American sockeye salmon populations and is thought to relate to temporal variation in both migration conditions for adults and spawning and rearing conditions in tributaries (Tagaki and Smith 1973; Merritt and Roberson 1986; Hodgson and Quinn 2002). For example, Columbia River and interior British Columbia stocks of sockeye salmon tend to enter fresh water before peak summer temperatures and hold in spawning tributaries for 1 month or more before fall spawning whereas coastal stocks migrate after peak temperatures just prior to spawning (Gilhousen 1990; Hodgson and Quinn 2002). Quinn and colleagues (Quinn and Adams 1996; Quinn et al. 1997; Hodgson and Quinn 2002) have used dam counts and historical records to examine the relationships between run timing and environmental conditions. They found that sockeye salmon passed Bonneville Dam progressively earlier over the period 1949–1993, concomitant with a progressive increase in the mean temperatures that migrating adults experienced in the lower Columbia River (Quinn and Adams 1996). Patterns of individual mortality during 1997 in relation to run timing and temperature were consistent with selection for earlier run timing within these populations, as hypothesized by Quinn and Adams (1996).

If such selection is real and leads to evolution of earlier run timing, we speculate that the energetic costs of migration will increase in coming decades. Recent regional climate projections predict increasingly early winter snowmelt, longer dry periods during summer, and later onset of fall conditions (Parson et al. 2001). If true, these conditions would lead to continued selection for early run timing in Columbia River sockeye and other spring-run salmonids. The energetic costs of migration will likely increase because fish will either hold without feeding in spawning tributaries for longer periods or experience higher temperatures during migration if populations do not respond to selection as rapidly as conditions change or both. This increase in energetic cost could lead to greater in-river or prespawn mortality, particularly in warm years and for stocks migrating long distances.

Technical Report – 2006-3

Water Temperatures in Adult Fishways at Mainstem Dams on the Snake and Columbia Rivers: Phase 2 — Biological Effects.

by

Christopher C. Caudill, Tami S. Clabough, George P. Naughton, Christopher A. Peery

Idaho Cooperative Fish and Wildlife Research Unit &
Department of Fish and Wildlife Resources
University of Idaho
Moscow, ID 83844-1141

and

Brian J. Burke
NOAA Fisheries

Climate projections for the interior Pacific Northwest suggest higher summer temperatures, less winter snowpack, and consequently, longer, warmer summers with lower stream flows (e.g., Mote et al. 2005, Stewart et al. 2005). These projections suggest that management of the hydrosystem thermal regime will become increasingly important to the recovery of Snake River summer and fall Chinook salmon and steelhead, particularly late spring-early summer runs (e.g., summer Chinook) and early fall run groups that currently experience the highest temperatures (e.g. Snake River A-run steelhead). If current climate predictions hold, modifications to fishways to ameliorate ladder temperature differences could be an important component to the management of the Snake River Hydrosystem thermal regime.

- -- - -- - -

by

C. A. Peery and T. C. Bjornn

U. S. Geological Survey
Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, ID 83844-1141

Technical Report 02-1

WATER TEMPERATURES AND PASSAGE OF ADULT SALMON AND STEELHEAD IN THE LOWER SNAKE RIVER

conservative test results. Travel times between Ice Harbor and Lower Granite dams for chinook salmon trended upward when temperatures at Lower Granite Dam were higher, but travel times between the two projects for steelhead were not significantly related to prevailing water temperatures. In short, we saw evidence that some chinook salmon and steelhead would delay entry into the Snake River during warm water conditions and some chinook salmon, but not steelhead, traveled slower through the lower Snake River when water temperatures were high. In contrast to radio-telemetry data, there was a relatively good correlation between when the first quartile of salmon and steelhead were counted at Ice Harbor and Lower Granite dams and water temperatures. Fish passed the dams later on years when average summer-time water temperatures were high, additional evidence that some salmon and steelhead will delay their upstream migration to avoid warm water conditions.

The second behavioral response to water temperatures by salmon and steelhead we saw was a delay by some fish in passing dams when temperatures were unfavorable, when temperatures exceeded 20°C and when there was a noticeable difference in temperatures between the tailrace and forebay surface, creating a sharp delineation where these two sources of water met in the fishways. Ironically, this condition was

Hydrosystem, Dam, and Reservoir Passage Rates of Adult Chinook Salmon and Steelhead in the Columbia and Snake Rivers

MATTHEW L. KEEFER,* CHRISTOPHER A. PEERY, THEODORE C. BJORNN,[1] AND MICHAEL A. JEPSON

Idaho Cooperative Fish and Wildlife Research Unit, Biological Resources Division, U.S. Geological Survey, University of Idaho, Moscow, Idaho 83844-1141, USA

LOWELL C. STUEHRENBERG[2]

Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, Washington 98112-2097, USA

Transactions of the American Fisheries Society 133:1413–1439, 2004

Fall Chinook salmon migrations were characterized by low discharge, especially in 2001. Migration rates from Bonneville Dam to McNary Dam decreased significantly in 2001, but not significantly in 2000, as discharge increased (Table A.1). Fall Chinook migrated significantly faster as temperatures decreased in 2000. The relationship was parabolic in 2001; passage rates were lowest when water temperatures were warmest and, again, late in the migration when temperatures were low.

Fallback.—For all years combined, 19% of spring, 8% of summer, and 3% of fall Chinook salmon fell back over and reascended a dam at least once before passing McNary Dam (Table 4).

High water temperature during upstream migration has been linked to higher prespawning mortality for spring Chinook salmon (Schreck et al. 1994), summer and fall Chinook salmon (Dauble and Mueller 2000), and sockeye salmon (Major and Mighell 1967) within the Columbia River basin; sockeye salmon in the Fraser River, British Columbia (Gilhousen 1990); and for steelhead in several systems (Baigun et al. 2000). Maximum river temperatures in all years of this study were within the range that could block adult migration (McCullough et al. 2001). Exposure to elevated water temperatures can increase susceptibility to disease and compromise reproductive performance through increased metabolic demands, reduced allocation to gonadal development, and reduced egg viability (Berman and Quinn 1991; Rand and Hinch 1998; Torgersen et al. 1999; Hinch and Rand 2000; Kinnison et al. 2001). In the Columbia basin, use of thermal refugia may ameliorate some costs of high main-stem temperatures, particularly for steelhead that pass through the lower river 6–10 months before spawning. However, obligate migrants, such as summer and fall Chinook, may be compromised by temperature-related delays and exposure to sublethal temperatures that could elevate metabolic costs, alter energy allocation, or delay arrival at spawning grounds.

dams. High water temperatures slow some migrants, especially steelhead and fall Chinook salmon that pass through the lower river between July and September. Studies that more fully examine relationships between spawning success, migration delays, fallback, temporary straying, and sublethal temperature exposure are needed to evaluate the reproductive costs and population-level effects of migration through the hydrosystem for adult fish. Large-scale, multiyear telemetry studies us-

■ -- -- -- -- -- -

FINAL REPORT

STOCK ASSESSMENT OF COLUMBIA RIVER
ANADROMOUS SALMONIDS

VOLUME I: CHINOOK, COHO, CHUM AND SOCKEYE SALMON STOCK SUMMARIES

by

Philip Howell
Kim Jones
Dennis Scarnecchia
■ Oregon Department of Fish and Wildlife

SNAKE RIVER FALL CHINOOK

Sex ratio

Richards (1961) obtained sex ratio information throughout the spawning period and found it to be 0.5:1 male to female. He also found that the ratio varied considerably among individual surveys.

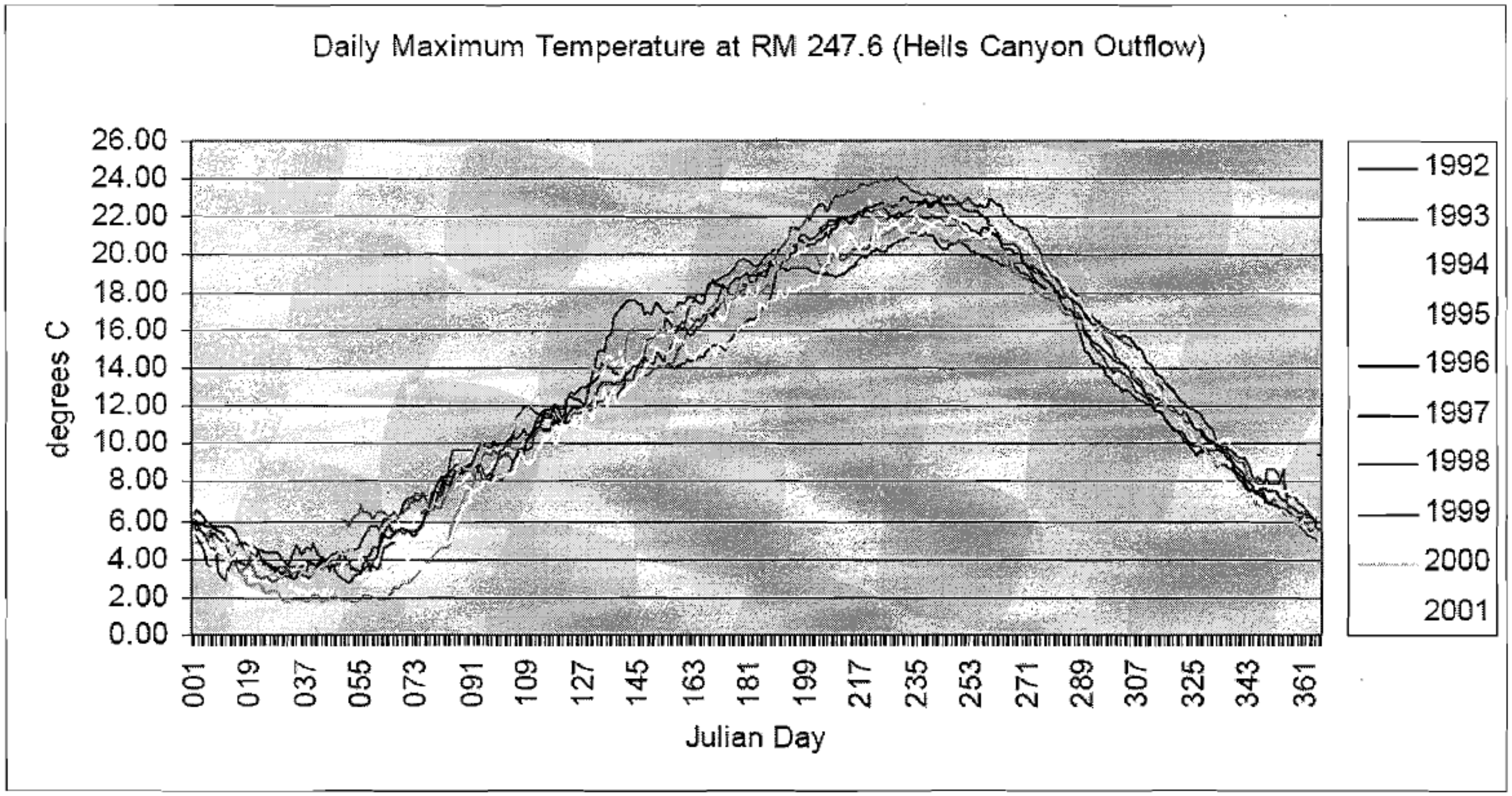
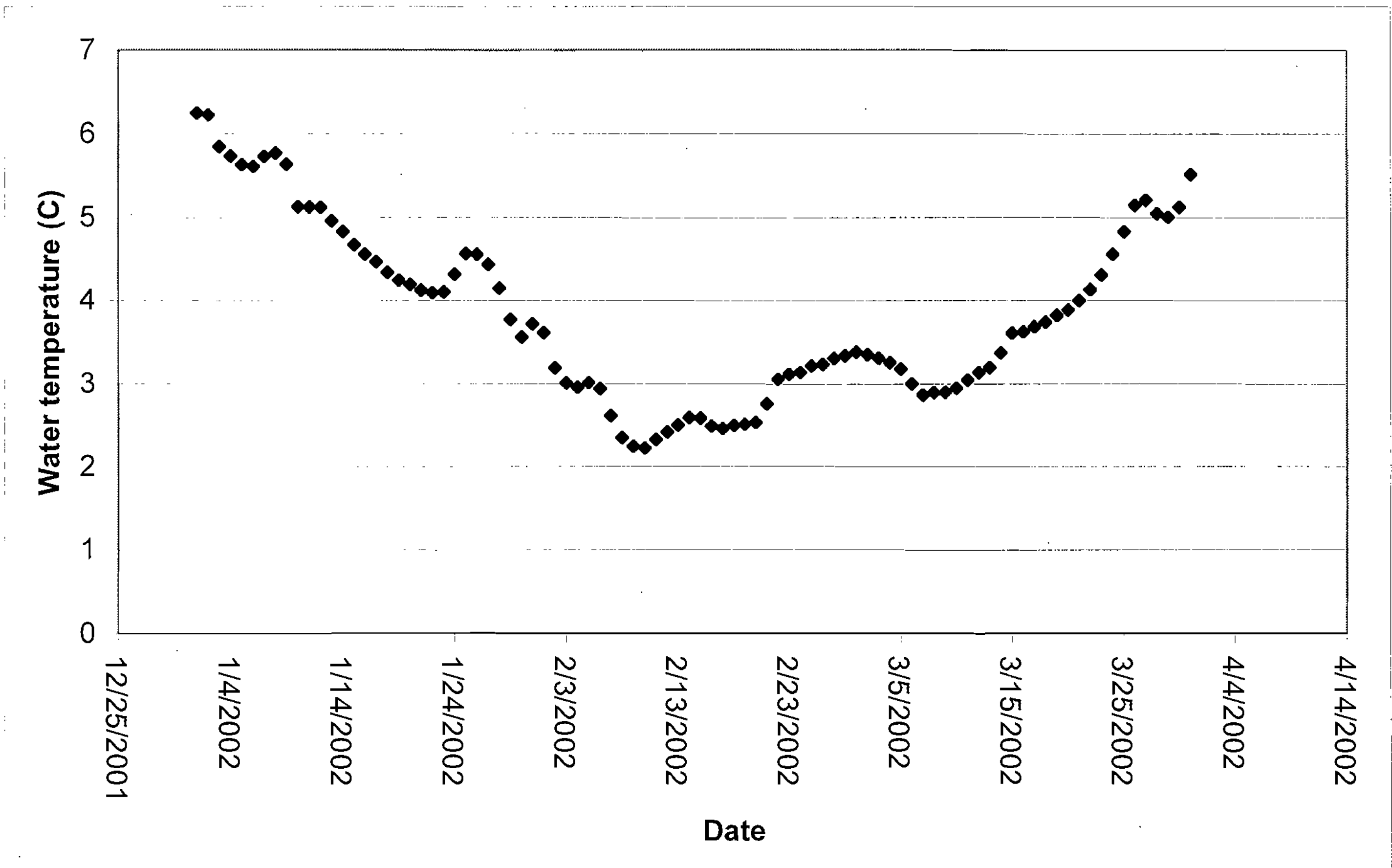


Figure 3.6.2 e. Water temperatures for the Downstream Snake River segment (RM 247 to 188) of the Snake River - Hells Canyon TMDL reach near Hells Canyon Dam.

Temperatures at RM 247.6 on the Snake River below HCD during the winter-spring of 2002. Based on data provided by IPC to ODEQ. Graph by McCullough (CRITFC, 2007).



Lower Snake River Water Quality
And Post-Drawdown Temperature
And Biological Productivity Modeling Study

Prepared for:
Department of the Army
Walla Walla District
US Army Corps of Engineers
201 North Third Avenue
Walla Walla, Washington 99362

Prepared by:
Normandeau Associates, Incorporated
25 Nashua Road
Bedford, New Hampshire 03110-5500
and
Department of the Army
Walla Walla District
US Army Corps of Engineers
May 1999

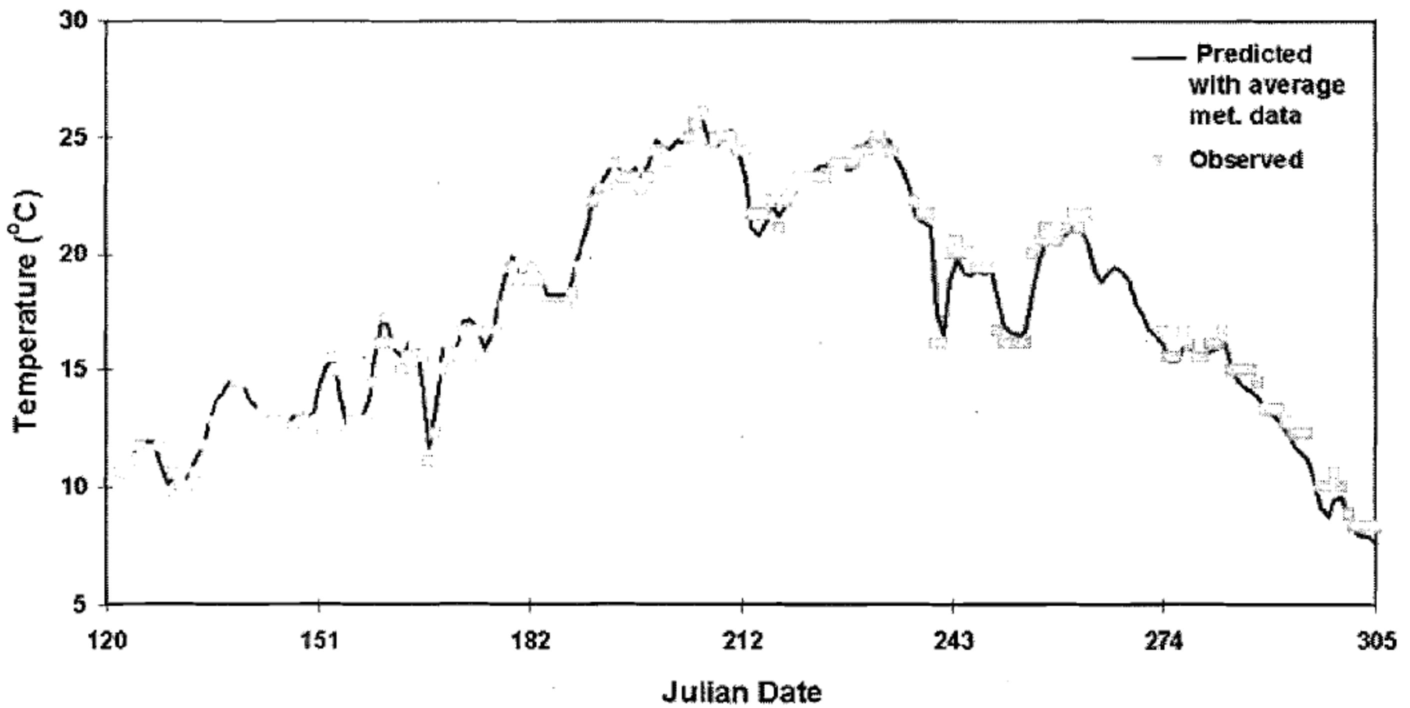


Figure 5.4-13. 1956 water temperatures at Central Ferry

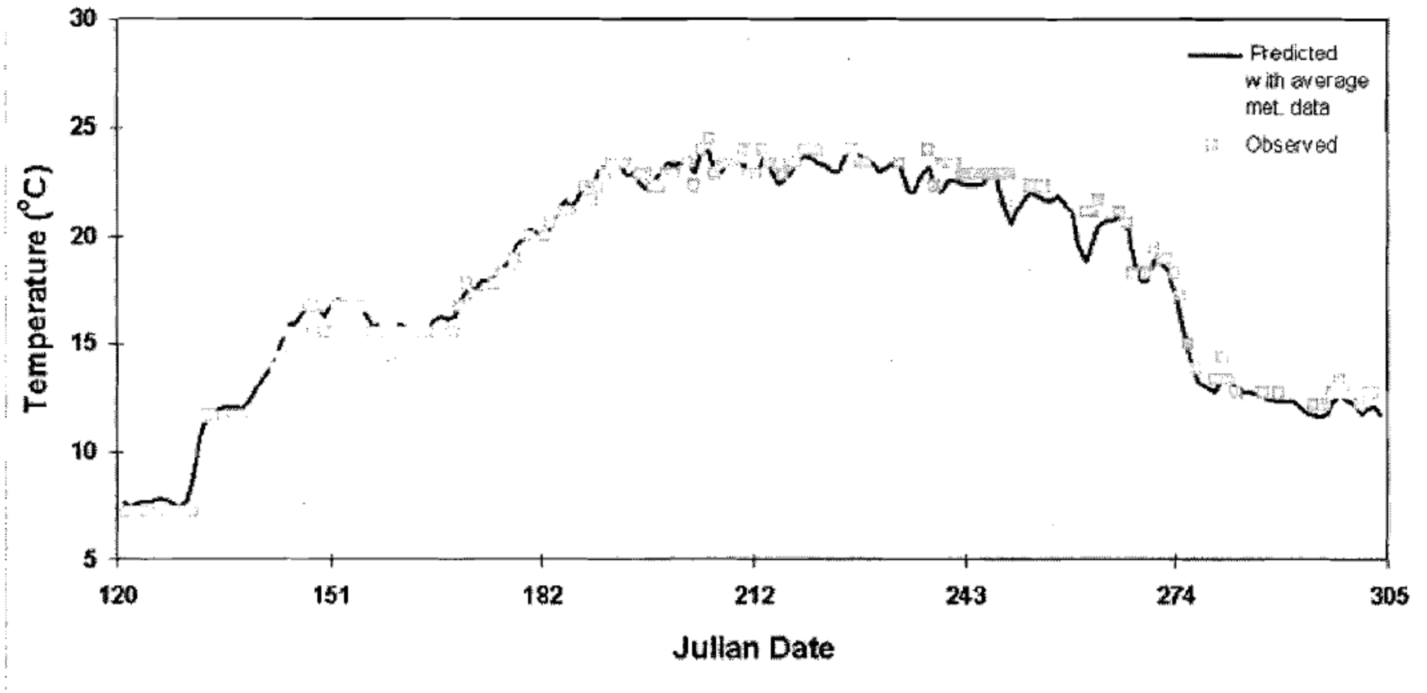


Figure 5.4-15. 1957 water temperatures at Central Ferry

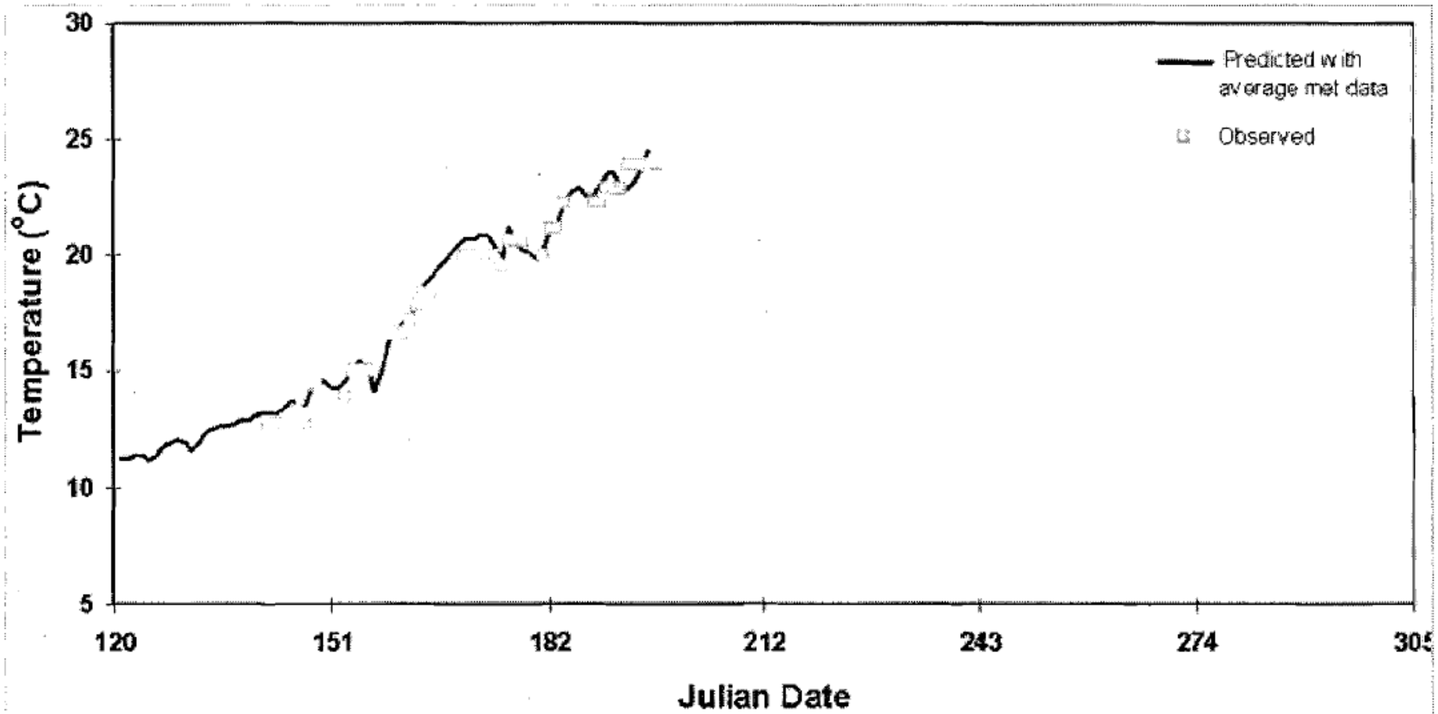


Figure 5.4-17. 1958 water temperatures at Central Ferry

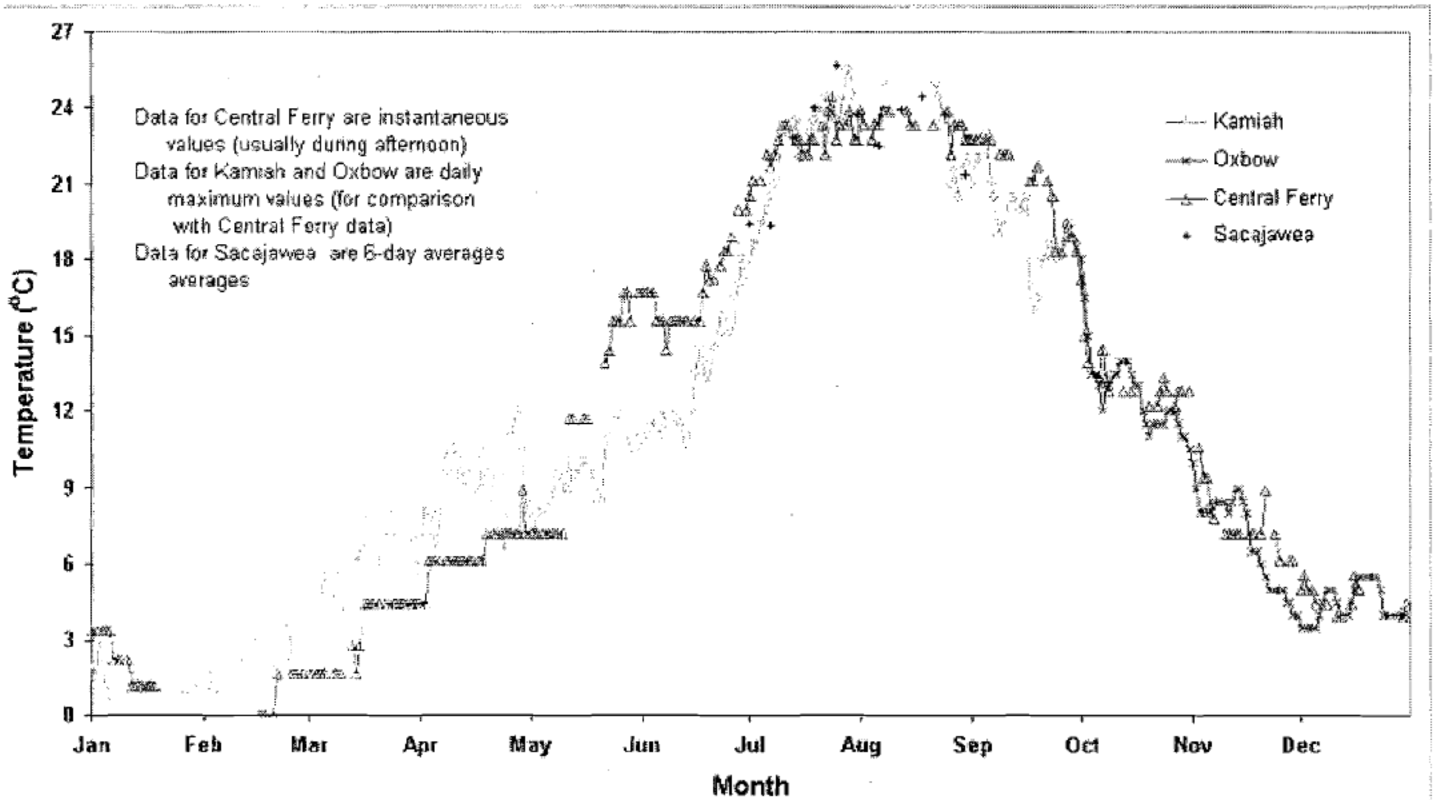


Figure 5.4-8. 1957 Snake River and Clearwater River water temperatures

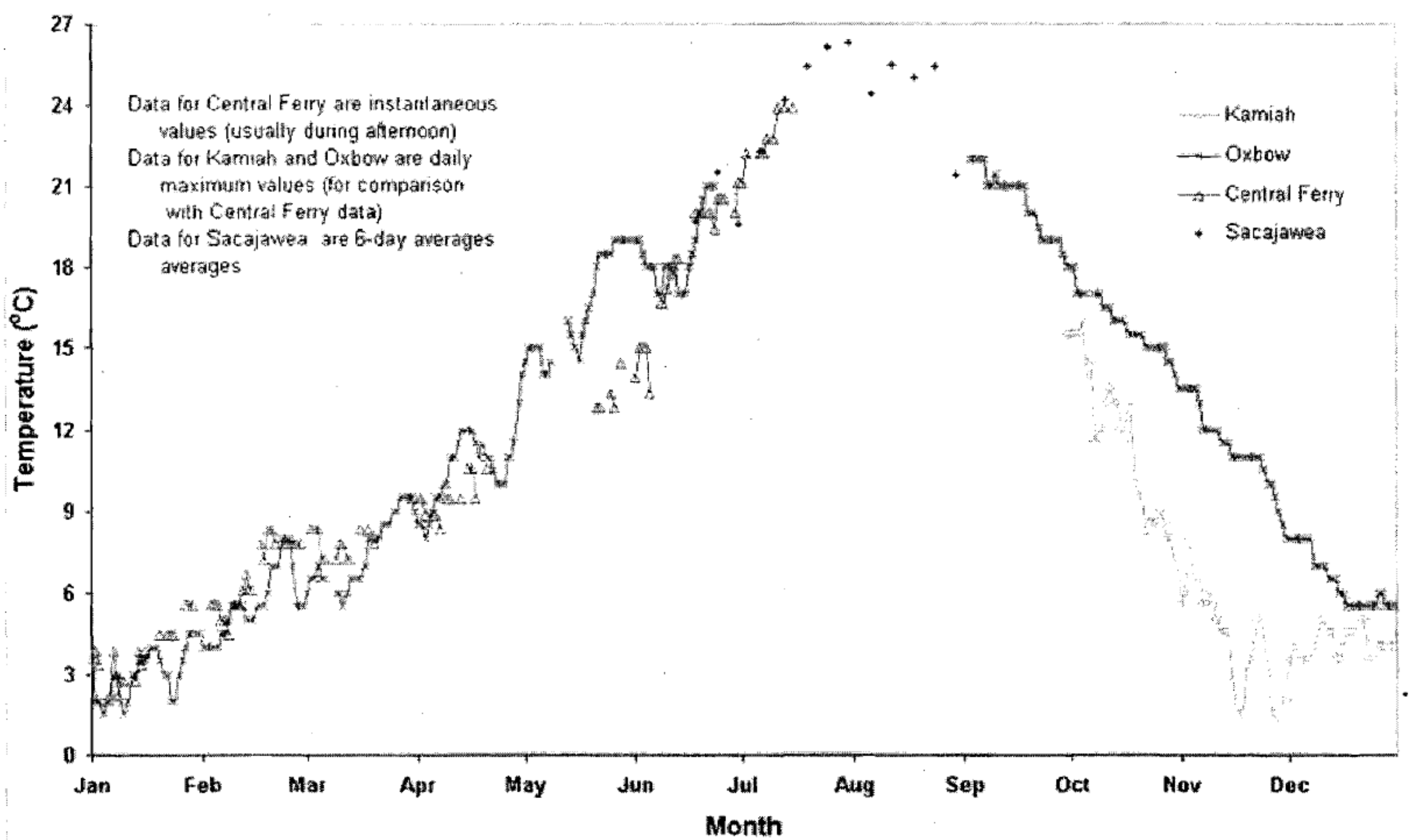


Figure 5.4-9. 1958 Snake River and Clearwater River water temperatures

Table 5.4-6
Listing of Stations with Observed Temperature Data Prior to Mid-1960's

Location	River Mile	Period of Record	Data Frequency	Data Source
Snake River at Sacajawea	(near mouth)	June through September for each year, 1955 through 1958	6-day averages	Graph of data provided by the Corps
Snake River at Central Ferry	83.2	October 1955 to July 1958	Instantaneous daily measurements	Copies of original USS data sheets provided by the Corps
Snake River near Clarkston (11343500)	132.9	October 1959 to September 1964	Daily min/max	Hydrosphere, Inc., CD (data originally from USGS)
Snake River near Anatone (13334300)	167.2	October 1959 to present	Daily min/max (prior to 1978)	Hydrosphere, Inc., CD (data originally from USGS)
Snake River at Oxbow (13290200)	269.6	October 1957 to September 1973	Daily min/max	Hydrosphere, Inc., CD (data originally from USGS)

UNITED STATES OF AMERICA

FEDERAL ENERGY REGULATORY COMMISSION

Idaho Power Company	Project No. 1971-079 Hells Canyon Hydroelectric Project
Application for New Major License Hells Canyon Project On the Snake River, Idaho	REVIEW OF THE JULY 2007 WHITE PAPER SUBMITTED BY IDAHO POWER COMPANY WRITTEN BY GROVES, ET AL BY DALE A. MCCULLOUGH

CERTIFICATE OF SERVICE

I hereby certify that I have this day complied with the Federal Energy Regulatory Commission's rules regarding service by serving this filing upon each person designated on the official service list compiled by the Secretary in this proceeding.

Submitted this 30th day of August, 2007.

Ryan Sudbury
Attorney for the Nez Perce Tribe

IDAHO POWER®
An IDACORP Company

JAMES C. TUCKER
Senior Attorney

May 2, 2008

Honorable Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, DC 20426

Reference: Project No. 1971-079—Idaho/Oregon
Hells Canyon Project
Idaho Power Company
Response to Nez Perce/CRITFC Review of Temperature White Paper

Dear Secretary:

By letter dated July 30, 2007, the Idaho Power Company submitted a White Paper entitled: *The Effects of the Hells Canyon Complex Relative to Water Temperature and Fall Chinook Salmon* (Groves/Chandler/Myers 2007) to the FERC for filing in the above matter. That Temperature White Paper comprehensively reviewed and analyzed Hells Canyon Complex temperature effects against the literature and the Company's own gathered data and concluded based on the best available science, that the temperature effects of the Hells Canyon Complex are benign or beneficial to Fall Chinook Salmon.

On August 30, 2007, the Nez Perce Tribe filed with the FERC its review of the Company's Temperature White Paper. (See: McCullough, D., *Review of Groves, Chandler and Myers (2007)*, Columbia River Inter-Tribal Fish Commission (CRITFC), August 27, 2007.) Enclosed for filing is the Idaho Power Company's response to the Nez Perce Tribe/CRITFC review of the Temperature White Paper.

If you have any questions, please do not hesitate to contact me.

Respectfully submitted,

James C. Tucker

cc: Service List

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1221 W. Idaho St.
Boise, ID 83702

IPC's Evaluation of the Nez Perce Tribe's Review of the Temperature White Paper

In July 2007, Idaho Power Company filed its Temperature White Paper with FERC. See Groves, P.A., Chandler, J.A., and Myers, R.; 2007; "White Paper: The Effects of the Hells Canyon Complex Relative to Water Temperature and the Fall Chinook Salmon." ("Temperature White Paper.") That exhaustive review concluded that with the exception of a very small number of redds that in some years are exposed to water temperatures greater than 16 ºC, there is no evidence that the thermal shift caused by the construction of the HCC adversely affects fall Chinook salmon. In fact, the thermal shift created by the HCC provides an overall benefit to the population of Snake River fall Chinook salmon by creating conditions in the reach below Hells Canyon Dam that can now sustain the only spawning and rearing area accessible to and suitable for fall Chinook salmon in the Snake River. Prior to construction of the HCC, this reach of river did not support significant spawning, primarily because it was a very cold environment. The thermal shift increased the rate of thermal unit accumulation experienced by incubating fall Chinook salmon by extending the cooling period in the fall and maintaining warmer over-winter temperatures better suited for incubation than what occurred pre-project. This allowed emergence timing to be very similar to reaches upstream of the HCC that historically supported major spawning and incubation areas in the Snake River, reaches that are now too degraded to support spawning and incubation. Further, this thermal shift has allowed maintenance of the ocean-type life history whereby fall Chinook salmon juveniles migrate as an Age-0 fish following only a brief rearing period. This life history can be maintained because these fish are able to incubate and grow fast enough to migrate before water temperatures in the lower Snake River reservoirs become too warm. This is distinct from the later emerging fall Chinook salmon from the Clearwater River and other colder environments. These fish are only able to survive the migratory delay in the lower Snake River reservoirs because of the addition to the Snake River of colder summer water from Dworshak Reservoir that allows those later migrants to over-summer and move to the ocean as a yearling fish.

On August 30, 2007, the Nez Perce Tribe filed with FERC its review of IPC's Temperature White Paper. See McCullough, D., "Review of Groves, Chandler, and Myers (2007)", Columbia River Inter-Tribal Fish Commission, August 27, 2007 ("CRITFC.") In its review, the Tribe states at the outset that "[t]he work put into this IPC review was substantial and was thoughtfully done. Also, much new information was brought forward to this complex discussion that is useful in getting a fuller appreciation of the issues." CRITFC at 1. Nevertheless, the review takes exception to the Temperature White Paper's conclusions. It concludes that the current temperature regime below Hells Canyon Dam is "a detriment to the Snake River fall Chinook." Id. It also raises certain issues about the efficacy of the Ehist model. Id. at 22.

The Tribe's contention that the current temperature regime below Hells Canyon Dam is a detriment to fall Chinook salmon is not well taken. After carefully reviewing results from studies used by CRITFC for supporting evidence, IPC biologists have noted that those study reports have often not undergone critical peer-review, contain various flaws, and tend to overstate specific findings while ignoring other findings, as well as failing to completely analyze data presented in those studies. Also, studies conducted on other species are consistently cited (i.e., sockeye salmon), which likely have little comparative value when assessing conditions for fall Chinook salmon. It is also apparent from its review of this topic that CRITFC fails to accord the proper deference to standard scientific principles. Throughout the White Paper, IPC endeavored to obtain and use information that has undergone either peer-review or has strong results based on rigorous scientific method, i.e., replicated samples providing statistically quantifiable and testable data that allow for the inclusion of variation inherent in any biological population. However, CRITFC did not rely on peer-reviewed, testable data, and indeed often relied on point-data of questionable quality.

In this summary IPC evaluates each of the principal criticisms the review levels at the Temperature White Paper and explains why each is without merit. The more detailed Appendix attached to this summary details the analysis that underlies the evaluations presented here. In sum, the Tribe's critique cannot serve to negate the findings of the Temperature White Paper.

The IPC Temperature White Paper, which is specific to temperature effects on fall Chinook salmon, covers eight major areas. The CRITFC reviewed each of these eight major areas as well as commented on the use and application of Ehist, an estimate of historic water temperatures.

The most important point to observe is that the Temperature White Paper was written in an effort to discuss potential effects on fall Chinook salmon due to changes in Snake River water temperature just prior to and following construction of the Hells Canyon Complex of dams and reservoirs. The paper was not intended to explore and produce conjecture on what the thermal character of the Snake River was prior to any water development projects being in place. The Tribe's review suffers from failing to proceed in parallel.

Section 1. Adult Migration

There is no evidence that the timing of adult fall Chinook salmon migration into the Snake River has been altered. While thermal conditions may have been altered within the Snake River after the construction of the HCC (especially due to Brownlee Reservoir), the timing of adult migration has not been altered. Within the context of altered adult migration timing, CRITFC cites a recent paper (Salinger and Anderson 2006) to support the position that the optimal swim speed temperature for adult Chinook salmon (all stocks combined, i.e., spring, summer, and fall) is 16.3°C. This appears reasonable, and as the authors of that paper noted, comports well with other studies. IPC does not find fault with this analysis. However, stating just what the "optimal" temperature for swim speed is (as CRITFC has done) is misleading. The authors of that paper also noted that swim speeds decline both above and below this temperature. This work indicates that, based on temperature, a proportion of the population will always experience a theoretical passage delay between Bonneville and Lower Granite Dam (distance of 462 km) when water temperatures differ from 16.3 °C. While 16.3 °C may be the temperature at which adult Chinook salmon theoretically swim the fastest (with reduced speed occurring above and below that temperature), the river system does not naturally remain stable at that temperature during the Chinook salmon migration period (March through November). CRITFC did not explore this additional information provided in the report; this is unfortunately a common error in the review.

Section 2. Pre-spawn Mortality

Regarding pre-spawn mortality, IPC maintains that there is no data that indicates or suggests that excessive pre-spawn mortality is occurring within the Snake River. Nor is there data to lend support or credence to the hypothesis that elevated water temperature is causing increased pre-spawn mortality of fall Chinook salmon. Even first-hand observation of the river corridor over 17 seasons of data collection, during early spawning surveys, does not reveal the potential for increased (or any) pre-spawn mortality.

As a further example of how CRITFC used non peer-reviewed papers as support for hypotheses, please note the reference to Keefer et al. (2004). While CRITFC uses this paper as “evidence” that increased incidences of pre-spawn mortality of fall Chinook salmon occur within the Snake River, the paper actually contains no data, and only speculates that elevated water temperature might have an effect on pre-spawn mortality. Further, CRITFC references several reports by the California Department of Fish and Game, none of which contains any data that relates water temperature to pre-spawn mortality. However, they do note that pre-spawn mortality can be difficult to ascertain, and can be quite variable from year to year, mostly depending on the physical state of the fish prior to entering the freshwater system.

Section 3. Gamete Viability

CRITFC argues that fall Chinook salmon that enter the Snake River are immediately and constantly exposed to elevated temperatures that have a significant, detrimental effect on gamete viability. IPC disagrees with this point. IPC does not disagree that there are some studies on other, less thermally tolerant salmonids that indicate that elevated temperature can have an effect on gamete viability. However, the few studies that have been attempted on larger Chinook salmon have not provided any evidence that fall Chinook salmon are exposed to water temperature conditions within the Snake River that result in detrimental gamete production or viability.

Within the CRITFC review of the IPC White Paper, two recent studies are cited that are intended to provide support for the theory that elevated water temperature experienced by early migrating adult fall Chinook salmon reduce gamete viability. These reports are Mann and Peery (2005), and Berijikian (2006); neither has been subjected to peer-review. Nor does either of these reports provide data that supports the proposition that fall Chinook salmon in the Snake River are experiencing reduced gamete viability due to exposure to elevated water temperature conditions.

Section 4. Disease Susceptibility

IPC does not dispute the general proposition that prolonged exposure to elevated water temperature may lead to higher disease susceptibility, or that increased incidence of disease in a population of Chinook salmon could result in elevated pre-spawn mortality. However, as mentioned earlier, there is no evidence of increased pre-spawn mortality in the Snake River fall Chinook population, nor does it appear to be excessively elevated over other natural river/stream systems. Nor is there any evidence that the prevalence of disease within the population of Snake River fall Chinook salmon is excessive. IPC cites a 14 year data set (1993-2006) for the Snake River that shows a consistently low level of fish per redd ratio of approximately 3.2 (range 2.0-4.2), which does not suggest that a high incidence of disease, leading to increased pre-spawn mortality, occurs. CRITFC is critical of the use of fish per redd ratios, and provides a "what if" calculation of two different pre-spawn mortality estimates (with certainty that the elevated pre-spawn mortality is due to elevated temperature and increased disease) and a discussion of how both scenarios can result in the same fish per redd ratios. However, the scenarios postulated by CRITFC are not based on actual data and are not representative of anything other than speculation. Any number of theoretical scenarios could just as well be conducted, which could be just as easily biased to show that fish per redd ratios are in actuality much lower, and that no level of pre-spawn mortality exists at all. The "what if" examples CRITFC provides do nothing except provide a false appearance that disease within this Chinook salmon population is prevalent due to elevated water temperature, and that this leads to increased pre-spawn mortality.

Section 5. Spawn Timing

IPC is well aware that the State of Oregon uses the seven day average maximum temperature occurring ***after first spawning*** as the standard for salmonid spawning. Within the Temperature White Paper, IPC used the seven days ***prior to first redd observation*** for its analysis because it provides a more conservative approach, i.e., favoring the fish, for assessing the water temperature that is present during early spawning. Because redd surveys of the Snake River generally occur on a Monday, this means that new redds observed on the day of the survey were actually constructed during the week previous to when they were observed.

The table in the Temperature White Paper that was put together for the Snake River (Table 3) is meant to show that there is no consistent water temperature at which the fish begin to spawn. There is also no predictive power to the data. Finally, based on the data provided by Groves et al. (2007), there is no indication that "preferred" spawning temperatures are ≤13.0 °C. In fact, when the data from Table 3 are scrutinized carefully, it becomes apparent that the most common temperature at which spawning in the Snake River was initiated has been about 15.0 °C.

In all years, the water temperature in the Snake River, as spawning was initiated, was declining, even in 2001, when redds were observed on 9 October at a seven day mean temperature of 19.1 °C. That year, during the week prior, through the end of the week after redds were first observed, the daily mean water temperature declined from 19.7 to 17.4 °C (roughly a decline of 0.2 °C per day). IPC did not indicate (and does not suggest) that fertilization of gametes at temperatures as high as 19.1 °C would result in high survival of embryos.

Evidence for the pre-HCC spawn timing distribution does not come from the IDFG reports from 1958-1960. The best historical spawn timing data comes from the reports by Zimmer (1950, 1953). Based on all of the data provided in those reports, it appears that in the Marsing Reach of the Snake River spawning historically began during the first or second week of October, which is similar to what is observed in the contemporary spawning areas downstream of the Hells Canyon Dam. Data that Zimmer (1950, 1953) provides further indicates that peak spawning in the Marsing Reach historically occurred at a similar time as compared to what is presently observed downstream of the HCC (by the first to second weeks of November), and that spawning was completed during early December. Based on the best data available, there is no evidence that contemporary spawn timing has been altered with respect to historic timing, due to changes in water temperature, downstream of the Hells Canyon Dam.

Section 6. Incubation Survival

CRITFC is critical of merging data from different studies in order to conduct a relevant and thorough synthesis of the effects of water temperature on incubation survival. This type of analysis is quite valid, especially if those studies proposed similar hypotheses, were performed on similar species, and were conducted under similar conditions. By merging the data from the three studies in question, a rigorous statistical analysis can be completed that does not serve to create ambiguity in the results. The result is that an unbiased, scientific approach can be used to make an objective assessment of how naturally declining water temperatures may affect incubation survival of fall Chinook salmon embryos. The inclusion of data from the three studies in question allows for the introduction of natural variability into the analysis; this is paramount in a statistical evaluation of any natural population. It is thus inappropriate that in lieu of such an approach CRITFC uses specific, limited data from one of the studies.

There is no doubt that the process of setting a protective temperature standard was based on an abundant source of literature. Further, without relevant data, it seems reasonable that using the only available information (even if from constant temperature studies) could be a prudent way to set a temperature standard. However, when provided with a good, solid body of evidence that is contrary to the standard, and is applicable to a specific species within a natural setting, it also seems prudent and reasonable to use that data to set a "site-specific" standard that remains protective of the species. IPC continues to argue that naturally declining thermal regimes result in very different embryo survivals than what may be implicated through constant temperature studies, and that available data is sufficient to set a site-specific temperature standard for fall Chinook spawning and incubation within the Snake River.

Section 7. Effects of Intragravel Temperature

Data that CRITFC relied upon to support the proposition that redd temperatures (intragravel) are significantly warmer than water column temperatures come from studies that have collected data from the ambient, undisturbed substrate – not from natural or artificial redds (Geist et al. 1999; Geist 2000; Hanrahan et al. 2004; Arntzen et al. 2006; Hanrahan 2007). The data IPC collected in the Snake River, described by Groves et al.

(2007), and further described by Groves et al. (in press), was also collected at fall Chinook salmon spawning grounds, but from artificially created redds in close association with naturally created redds. The data IPC provided more closely represents the thermal conditions that would be expected to be present in naturally constructed redds. As well, other authors who have attempted to study either natural or artificial redds have noted the same type of findings (Ringler and Hall 1975; Vronskiy and Leman 1991; and Hanrahan 2007).

Section 8. Emergence/Outmigration Timing

Estimates of emergence timing of fry in the present-day Hells Canyon Reach (especially the upper section) is similar to historic estimates of emergence in the Marsing Reach (refer to Figure 5, page 16 of the Temperature White Paper), and has become more similar during recent years. Outmigration timing of juvenile, sub-yearling Snake River fall Chinook, observed at Lower Granite Dam, has been occurring earlier during the past few years (2000-2006) than what was observed during the 1990's. Not only has the timing advanced, it has become less protracted. The reason for this shift in outmigration timing and distribution is unknown; however, it is occurring earlier and is more like what was historically observed prior to the construction of the Hells Canyon Complex or the Lower Snake River dams. Were it not for the slack water conditions of Lower Granite Reservoir, the sub-yearling fall Chinook salmon emigrating from the Hells Canyon Reach during contemporary times would be passing through the Central Ferry region of the lower Snake River (downstream of the present-day Lower Granite Dam) at a time that would be comparable to what Mains and Smith (1964) described for sub-yearlings that allegedly emigrated from the Marsing Reach prior to the construction of the Hells Canyon Complex. CRITFC indicates that the recent trend in earlier emigration timing is due to the recent observation of a yearling life history strategy, most prevalent in very late emerging juveniles originating from the Clearwater River. The expression of a yearling life history strategy that is almost wholly characteristic of fish originating from the Clearwater River has absolutely nothing to do with the fact that the sub-yearling fish from the Snake River are exhibiting earlier emigration timing.

Section 9. Ehist

CRITFC is correct in noting that Ehist estimates during periods of missing data do not consider all factors that effect temperature, including air temperature and solar radiation. However, the claim that data provided by IPC do not indicate which days had synthesized data is not correct. The White Paper provides a summary of the Ehist methodology, but clearly and repeatedly references the January 31, 2007 Hells Canyon Complex 401 Water Quality Certification application as the source of Ehist details. Indeed, the information claimed to be lacking has been provided by IPC in Exhibit 6.1-2 of the 401 application. It appears CRITFC deemed the Ehist methodology flawed without reviewing the documentation that the White Paper references. CRITFC incorrectly states that Figures 6.1-3, 6.1-4, 6.1-5, and 6.1-6 were taken from the Snake River TMDL, when in fact they were reproduced from IPC's January 31, 2007, 401 certification application, which contains the information claimed to be lacking.

It appears that CRITFC misused the Ehist model in its analysis. Specifically, claiming the ability to define a significant amount of warming on October 1 using Ehist data by comparing the Ehist results with measured data is not valid. The model provides estimates of temperature trends and characterizes estimated historic temperatures. It is thus inappropriate to use the model to define an exact temperature that can be compared to measured present day outflow temperatures to quantify a specific-day temperature effect of the HCC.

In sum, CRITFC's critical evaluation of the Temperature White Paper is seriously flawed, and the IPC Temperature White Paper's conclusions remain sound.

Appendix to IPC's Evaluation of the Nez Perce Tribe's Review of the Temperature White Paper :

Groves, P.A., J.A. Chandler, and R. Myers. 2007. White Paper: The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon. Idaho Power Company, Boise, Idaho.

Adult Migration:

1. CRITFC appears not to have observed how IPC has used the term "historical." In the initial portion of this discussion (altered timing of adult migration), IPC referenced an EPA report that stated (with no data) that the historic adult migration of fall Chinook salmon into the Snake River occurred in late August through November, with a peak in September. IPC understands that "historical" refers to a pre-development period prior to the late 1800's. IPC has clearly pointed out that contemporary passage timing remains similar to what has been described as "historical" migration timing through the lower Snake River, and that this has not changed, even after construction of the HCC in the upper Snake River, the construction of four additional federal dams in the lower Snake River, and with the very recent operations from Dworshak Reservoir on the Clearwater River used to cool the lower Snake River.
2. In the context of what IPC is describing for adult migration, the water temperature data analyzed from the Central Ferry location on the Snake River portrays what the water temperature conditions were for the Snake River near the location of the present-day Lower Granite Dam prior to when the Hells Canyon Complex (or any of the federal lower Snake River dams) existed. Because the IPC paper is intended to compare conditions pre- and post- construction of the HCC, this is a valid point to consider. CRITFC correctly indicates that Dworshak Reservoir operations have been used in recent years to modify the water temperature in the Snake River throughout the Lower Granite Reservoir. However, even if data for the years when these operations occurred are omitted from any analyses, the timing of contemporary adult migration of fall Chinook salmon still remains the same as it did "historically". As well, during the time period (mid- to late-1950's) from which Central Ferry temperatures were obtained for comparison with present-day conditions, the population of fall Chinook salmon was considered healthy and abundant. Even if the thermal regime of the Snake River during the 1950's was already altered, this would not be an effect of the HCC because the HCC did not then exist. Again, the White Paper is intended to assess the thermal effects attributable to the construction of the HCC on fall Chinook salmon in the Snake River.
3. CRITFC cites a more recent paper (Goniea et al. 2006) to support the hypothesis that temperatures >20.0 °C significantly reduce rates of adult travel to spawning grounds. IPC has reviewed this paper, and agrees that elevated water temperatures can have an effect on adult migration timing. It appears quite clear from the data presented in the report that a reduced rate of migration (from about 40 km/day to

about 20 km/day) occurs between 21.0 and 22.0 °C. This is obvious from figure 5 and table 2 in Goniea et al. (2006). This report also claims that historic run timing at Bonneville and McNary dams has been altered due to water temperature. This claim is based on the difference during each year between the 75% and 25% passage timing at each of those projects. Based on the way the data is presented, there does appear to be an alteration in the run timing, with the inter-quartile ranges expanding over time. However, the actual data for the quartile passage dates indicates that the earlier 25% passage (presumably during warmer conditions) has not changed at Bonneville Dam since 1938, but that the 75% passage time (as well as the 90% passage time) have each become later and they are occurring when water temperatures are cooler. Also, there is no indication that water temperature has caused this to occur. There is strong indication that data from 1938-1979 shows no increase in the inter-quartile range, and that while data from 1980 through 2006 indicates a larger inter-quartile range, it has not increased throughout that period. The authors obliquely note this by stating that at the Dalles Dam, during the period 1977 to present, they could detect no increase in the inter-quartile range of adult fall Chinook salmon passage.

4. CRITFC cites another recent paper (Salinger and Anderson 2006) to support that the optimal swim speed temperature for adult Chinook salmon (all stocks combined, i.e., spring, summer, and fall) is 16.3°C. This appears reasonable, and as the authors noted, comports well with other studies. However, stating just what the "optimal" temperature for swim speed is can be misleading. The authors also note that swim speeds drop off both above and below this temperature. This work indicates that based on temperature a proportion of the population theoretically experiences a passage delay between Bonneville and Lower Granite Dam (distance of 462 km), as temperatures get warmer or cooler than 16.3 °C. The results indicate that passage delays increase by about 3.3 days at 17.0 °C, and by 4.7 days at 8.0 °C. At 21.0 °C the delay is estimated to be approximately 4.1 days, and at 13.0 °C about 3.9 days. These are very small differences even between the extremes, and it is difficult to believe that a potential migration delay of 4 days will result in a detriment to the population. More importantly, while 16.3°C may be the temperature at which adult Chinook salmon theoretically swim the fastest (with reduced speed occurring above and below that temperature), the question then becomes, should the entire lower Snake and Columbia rivers be maintained at 16.3 °C from approximately 1 March through 30 November every year (the basic time-frame of adult Chinook salmon upstream migration)? The question seems to answer itself in the negative.
5. CRITFC cites another recent paper (Naughton et al. 2005) to support the proposition that slowed migration is associated with cumulative effects of the hydrosystem and impairs migration success. This paper is specific to sockeye salmon. Sockeye salmon are much smaller than fall Chinook, and have less energy stores with which to cope with elevated bio-energetic needs at elevated water temperatures. This is one reason why sockeye salmon do not tolerate elevated temperature conditions as well as Chinook salmon do. The sockeye salmon that were reported to perform the worst, i.e., had the highest estimated in-river mortality, were tagged at Bonneville Dam in 1997 during the period 24 July

through 5 August. Water temperature in the forebay of Bonneville Dam during 1997 was consistently over 20.0 °C from 24 July through 21 September, and was elevated over 22.0 °C from 10 August through 4 September. While temperature conditions generally cooled as the fish moved upstream, within the lower Columbia (downstream of Priest Rapids Dam) they continued to be subjected to water temperatures above 20.0 °C from about early-August through late-September. The median passage time for tagged sockeye salmon to move from Bonneville Dam to the forebay of Priest Rapids Dam was 13 days (range between 8.5 to >30 days). Certainly fall Chinook salmon were also within the lower Columbia River during the same time frame; their migration period at Bonneville Dam is managed as beginning 1 August. However, as noted previously, and throughout the IPC White Paper, sockeye and Chinook salmon have different biological responses to elevated temperature conditions, with Chinook salmon having a significantly higher thermal tolerance.

Pre-spawn Mortality:

1. IPC agrees that continual holding at elevated water temperatures (>19.0 °C) would likely result in elevated pre-spawn mortality of adult fall Chinook salmon. IPC also agrees that, depending on the year, temperature conditions in the Hells Canyon Reach of the Snake River (upstream of the Lower Granite Reservoir) can be ≥19.0 °C from mid-August through mid-September or early-October. However, CRITFC assumes that each year the entire population of adult fall Chinook salmon moves immediately into areas of elevated water temperature and is thereby subjected to poor environmental conditions. CRITFC also ignores the potential for cool-water refuges that likely exist throughout the free-flowing reach of the Snake River above Lower Granite Reservoir.
2. It is abundantly clear that CRITFC is not spatially familiar with the free-flowing reach of the Snake River. IPC agrees that Dworshak Reservoir releases assist in cooling the Lower Granite Reservoir, and provide a significant cool-water refuge for adult fall Chinook salmon at the upper end of Lower Granite Reservoir. As well, there are several potential cool-water refuges throughout the free-flowing reach of the Snake River between the upper end of the Lower Granite Reservoir and the Hells Canyon Dam. IPC listed the larger tributaries (Grande Ronde, Salmon, and Imnaha rivers), as well as a large number of smaller tributaries, that are distributed throughout the free-flowing reach and which can provide significant thermal refugia for adult fall Chinook salmon, and which are not highly distant from spawning grounds. As one major example, the Grande Ronde River cools appreciably by the first of September, and its plume remains relatively unmixed within the main Snake River for approximately two miles downstream. Five large spawning areas are within two miles of this plume. CRITFC mentions diversion and land-use practices on many of the smaller tributaries that may affect their usefulness as thermal refugia. Again, it is apparent that CRITFC has no understanding of the Hells Canyon Reach, and that most of the smaller tributaries are within the boundaries of wildlife management areas or are within the boundary of the HCNRA, and as such are not appreciably altered due to diversions or poor land-use practices.

3. The Keefer et al. (2004) paper cited by CRITFC provides no data and therefore only speculation on potential pre-spawn mortality due to water temperature in the Snake River.
4. IPC does not agree that a 7 day average maximum temperature of 13.0 °C is necessary to protect spawning of fall Chinook salmon. The standard that has been developed is based on data from constant temperature incubation studies, most of which are specific to other salmonids, and does not represent natural environmental conditions.
5. CRITFC's review on this topic fails to accord the proper deference to standard scientific principles. Throughout the Temperature White Paper, IPC endeavored to obtain and use information that has undergone peer-review, or has strong results based on rigorous scientific method employing replicated samples providing statistically quantifiable and testable data that allow for variation inherent in any biological population. However, CRITFC relies consistently on point-data of questionable quality in lieu of peer reviewed data.
6. Data from the California Department of Water Resources concerning pre-spawn mortality indicates that pre-spawn mortality is difficult to ascertain, and can be quite variable from year to year, mostly depending on the physical state of the fish prior to entrance into the freshwater system. Their reports actually provide no data that is useful in determining how temperature affects pre-spawn mortality, or how to use temperature data to assess or estimate pre-spawn mortality. IPC submits that pre-spawn mortality within the Snake River is not excessive and in fact is similar to other river systems throughout the Pacific Northwest.
7. The Brown and Geist (2002) paper cited by CRITFC concerning the potential of pre-spawn mortality states this in its Executive Summary: **"Out of necessity, we captured fish which already had passed through difficult passage conditions. Thus, our study protocol may have biased our results. All of the fish used in our study were captured while trying to pass Lyle Falls, tagged, and then returned downstream where they were released. Thus, the fish tracked during this study likely had lower energy reserves and were more mature than fish that were approaching the lower river for the first time. This factor should be weighed when interpreting results."** CRITFC appears to have ignored or unreasonably discounted this important caveat.
8. It is also important to note that migration rates of fall Chinook salmon in the Klickitat River study of Brown and Geist (2002) averaged a little over 2.0 km/day (range between about 0.8 – 3.8 km/day, depending on type of tag used), while fall Chinook tagged and followed within the Columbia and Snake River tend to have average migration rates between about 20.0 to 40.0 km/day (Goniea et al. 2006). CRITFC misuses the lower migration rate of Klickitat fish as a surrogate for Snake River fall Chinook in order to support the theory that delayed migration of Snake River fall Chinook salmon, due to very low migration rates, results in elevated pre-spawn mortality. In reality, Snake River fall Chinook migrate upriver at significantly faster rates.
9. The Brown and Geist (2002) study was specifically aimed at determining how the use of stored energy through fast velocity water and during attempts to pass multiple barriers, such as large falls, may affect the potential for fish to reach their

spawning grounds in relatively good shape and health. Their findings determined that multiple large falls and long reaches of fast velocity water, with very little velocity refugia, in the Klickitat River may be depleting energy stores and leading to upstream migration delays of between 9-11 days. This has very little relevance or comparative value to the Columbia/Snake River system.

Gamete Viability:

1. CRITFC continues to argue that fall Chinook salmon that enter the Snake River are immediately and constantly exposed to elevated temperatures that have a significant, detrimental effect on gamete viability. IPC disagrees with this point. IPC agrees, for the little it is worth in this context, that there are some studies on other, less thermally tolerant salmonids that indicate that elevated temperature can have an effect on gamete viability. But this does not necessarily say anything about fall Chinook, and in fact the few studies that have been attempted on larger Chinook salmon have not provided any evidence that fall Chinook salmon are exposed to water temperatures conditions within the Snake River that will lead to detrimental effects on gamete production or viability.
2. The Mann and Peery (2005 – *not 2004*) is quite recent, and IPC was not aware of it at the time the White Paper was completed. CRITFC uses the results from this study to support the assertion that elevated Snake River water temperatures have a detrimental effect on gamete viability in fall Chinook salmon. But the data presented in this report do not provide any, let alone any strong evidence for this contention. The authors state that, "Five fish with the highest temperature exposures, calculated as degree days above 20.0 °C, had five of the six highest mortalities for both stages of embryo development" (Mann and Peery 2005). This statement is true, but is also misleading if not properly explained. The actual data is more enlightening. Of the 13 females that had useable thermal exposure data prior to spawning, the final embryo mortalities of 12 were all <9%, and 10 were less than 6% (mean eye-up mortality 4.0%, range of 0.5-19.5%; mean button-up mortality 4.9%, range of 1.4-19.8%). Only the progeny from a single female had embryo mortality as high as ≈20%, and that one female was exposed to the ***coolest*** water temperatures (median temperature = 17.5, maximum temperature = 18.5, degree days >18.0 °C = 0.3, degree days >20.0 °C = 0). The authors provided a plot of embryo mortality as a function of degree day exposures, but failed to provide analyses of these relationships, which remarkably, all have r^2 values of <0.05, and are not significant. Finally, the data can be analyzed as an "exposure vs. non-exposure" experiment, with an hypothesis asking whether there is a difference in embryo mortality for gametes from adults that were exposed to water temperatures above 20.0 °C, and those that were not. The resultant P-values for the eye-up and button-up mortalities, are 0.655 and 0.709, respectively, indicating that there is no evidence for claiming a difference in embryo mortality based on exposure to elevated water temperature. Further, CRITFC misquotes references: the CRITFC review states that fish that had been "exposed to temperatures as high as 23.6°C during migration had a high incidence of embryo mortality" (CRITFC page 8) In fact, for the embryo mortality tests conducted by Mann and Peery (2005), the highest temperature to which adults were exposed

(adults which had data that could be analyzed) during the pre-spawn period was 21.9 °C. There were fish that were exposed to temperatures as high as 23.6 °C, but their gametes were not used in the embryo mortality tests, and did not provide any data or information concerning the effect of adult temperature exposure and gamete viability Contrary to CRITFC's review, the most recent report edited by Berijikian (2006) provides no evidence of altered gamete viability due to elevated adult thermal exposure. Further, it should be pointed out that these series of studies are not representative of fish in a natural environment, but rather are tests on spring Chinook salmon that have been bred and reared their entire lives within a captive broodstock environment. The report does allude to the possibility of slightly advancing ovulation timing (and theoretically spawn-timing) by providing a cooler pre-spawn environment during the ocean portion of their lives; however, this point was not strongly supported by the results. Nonetheless, the following is taken directly from the Berijikian (2006) report:

a. "The number of eggs retained at death did not differ significantly among treatments (U=53, P=0.514).

b. "The number of fry produced by chilled and ambient females did not differ significantly (U=40.0, P=0.277)"

c. "The two ambient females that spawned had estimated egg-to-fry survival of 10% and 34%, and egg-to-fry survival of the three chilled females was 4%, 20%, and 42%." (Note that the mean for ambient and chilled test subjects was 22%).

d. "We hypothesized that a more natural (cooler) seawater temperature profile would improve reproductive performance. The results suggest that this factor alone is not responsible for the poor reproductive success of captively reared Chinook salmon in this study and indications of poor breeding success in previous investigations of captively reared Chinook salmon (Berijikian et al. 2001, 2003)."

Disease Susceptibility:

1. Fish counts collected at the lower Snake River dams do include jacks. Counts at Lower Granite Dam are separated into both jacks and adults. Fish to redd ratios for the Snake River upstream of Lower Granite Dam are calculated using only the adult portion of the count.
2. There is annual variation in the female to male ratio within the adult (excluding jacks) portion of the Snake River fall Chinook population. There is no data available concerning the female to male ratio for the portion of the population that is allowed to escape upstream of Lower Granite Dam. However, there is data on this topic for the fish that are collected at Lyons Ferry Hatchery on the Lower Snake River. That data shows that between 1991 and 2002 the percentage of females in the adult portion of that population has been 0.48 (range of 0.27-0.53). In order to use this data we have to assume that the portion of the population that is allowed to escape upstream of Lower Granite Dam has a similar female to male

ratio. Using these data and an estimate of overcount at Lower Granite Dam, the female to redd ratio between 1993 and 2006 has averaged 1.3 (range of 0.9-1.8). We exclude data prior to 1993 because of significant differences in how redd counts were collected in earlier years. If our redd counts and adult counts were perfect we would expect the female to redd ratio would be 1.0 – indicating that each female in the population survived and completed one redd. CRITFC is correct in pointing out that our redd counts are not perfect, and that is one reason why we do not (and will not ever) have consistent female to redd ratios of 1.0. One crucial reason for this is that it is likely that we will never be able to obtain a complete census of all redds constructed at water depths greater than about three meters. While deepwater video searches are conducted throughout the Hells Canyon Reach of the Snake River, indicating that an average of about 30% of the redds in that system can be at depths greater than three meters, we are quite certain that for reasons beyond our control every single redd is not counted. More importantly, deepwater redd searches are not conducted in the Clearwater River, where the potential exists for deepwater spawning to occur. So, while the female to redd ratio (based on the best available data) averages 1.3, it is more than likely lower than that. As any reviewer would likely point out, a female to redd ratio of 1.3 indicates that there are either redds not being accounted for, females in the population that are not constructing redds, or a percentage of the population that is perishing prior to spawning, and that approximately 23% (ranging between 0-44%) of the female population is being lost to prespawn mortality (due to disease or a myriad of other factors). As mentioned earlier, we are certain that we are not counting every single redd (we would expect that the true female to redd ratio would be less than 1.3). Also, in any population there is always some level of prespawn mortality – even due to disease – that occurs (again, the true female to redd ratio would be less than 1.3). Based on reports from other systems, a level of prespawn mortality ≈23% is not excessive. Because the female to redd ratio is so consistent from year to year, and has a very narrow range, it does not suggest that some dynamic event is occurring within the Snake River that triggers massive outbreaks of disease or prespawn mortality.

3. A female can dig more than one redd, and it is quite possible that a female may construct a redd and actually never spawn. However, this occurrence is not known to be common within any population.
4. Turbidity can reduce the ability for observers to obtain good counts of redds. This actually occurs in most years along the Clearwater River, and is another reason why it is likely that our redd counts are not complete, and the fish to redd and female to redd ratios are not perfect. Because we do not count every single redd, the fish to redd and female to redd ratios in the Snake River basin are higher than what they truly are, which is another point indicating that excessive prespawn mortality is not occurring.
5. CRITFC conducted an interesting “what if” scenario for illustrating how the fish to redd ratios can mask a large amount of prespawn mortality (which is allegedly entirely due to temperature). We could conduct a similar exercise and posit that the fish to redd ratio averages 2.1, and is 2.0 one year, but is 2.2 the next year. It is possible that prespawn mortality could be 0% the first year and 0% the second

year. In each year 200 fish were counted passing the dam, yet in year one 100 redds were observed (ratio 2:1, or stated as 2.0), while in year two only 90 redds were counted (ratio 2.2:1, or stated as 2.2). The reason for the difference is that in year one, the observers actually got lucky and the female to male ratio was exactly 1:1, there was absolutely no prespawn mortality (not likely in any population) and the observers counted every single redd. However in year two, with similar conditions, the observers missed 10 redds that were constructed in the deepwater of one site that was not searched. Any number of potential scenarios could be "made up". None of them would have scientifically demonstrable value.

Spawn Timing:

1. IPC is well aware that the State of Oregon uses the seven day average maximum temperature occurring after first spawning as the standard for salmonid spawning. IPC used the seven days prior to when the first redds were observed for its analysis because it provides a more conservative approach for assessing the water temperature that is present during early spawning. Because Snake River redd surveys generally occur on a Monday, this means that redds observed on the day of the survey were actually constructed sometime during the week previous to when they were observed.
2. Evidence for the pre-HCC spawn distribution does not come from the IDFG reports from 1958-1960.
3. The table within the Temperature White Paper that was put together for the Snake River (Table 3) was meant to show that there is no consistent water temperature at which fall Chinook salmon begin to spawn. For the years 1991-2006, within the upper Hells Canyon Reach the mean temperature during the seven days prior to spawning was 15.7 °C, with a range of 12.5 – 19.1 °C; moreover, there is no predictive power to the data (one cannot predict when spawning will begin based on water temperature). Also, in all years, the water temperature was declining, even in 2001, when redds were observed on 9 October at a seven day mean temperature of 19.1 °C. During the week prior, through the end of the week after the first redds were observed, the daily mean water temperature declined from 19.7 to 17.4 °C (roughly a decline of 0.2 °C per day). IPC did not indicate that fertilization of gametes at temperatures as high as 19.1 °C would result in high survival of embryos.
4. IPC also intended to indicate with Table 3, that even though the water temperatures are cooler earlier within the lower Hells Canyon Reach, spawning in that reach does not consistently occur at an earlier date than in the upper Hells Canyon Reach. In only 4 of 16 years did spawning occur earlier in the lower Hells Canyon Reach, and in 5 of 16 years spawning occurred later in the lower Hells Canyon Reach. Cooler conditions did not consistently trigger earlier spawning within the lower Hells Canyon Reach. The most notable example of this occurred in 2000, when fish in the upper Hells Canyon Reach began spawning around 9 October at a water temperature of about 17.3 °C, while fish in the lower Hells Canyon Reach began spawning around 23 October at a temperature of about 13.6 °C. Based on the available data, and previous years' observations, it is

conceivable that the fish in the Lower Hells Canyon Reach could have begun spawning two weeks earlier (around 9 October) at a temperature of about 16.1 °C; or they could have begun spawning at least one week earlier at a temperature of about 14.3 °C. They did not, and as CRITFC points out, this could have been due to any number of reasons. What should be clear, however, is that water temperature does not provide a predictive element explaining why the later spawning occurred.

5. With the contemporary spawning and thermal data provided in Tables 3 through 5 of the Temperature White Paper, IPC is indicating that there is no consistent pattern that links the initiation of spawning to any particular temperature. In the end, it is not reasonable to expect spawning to be consistently initiated earlier just because water temperatures are reduced. However, IPC does not gainsay the possibility that spawning within the Snake River could begin earlier if the river were to be cooled substantially, by about 6.0 °C by the last week of September. However, based on the data that is available, while there would be no guarantee that spawning would actually begin earlier, this level of cooling would likely result in a delay in early emergence.
6. In summary, based on the data provided by Groves et al. (2007), there is no indication that preferred spawning temperatures are ≤13.0 °C.
7. The best historical spawn timing data comes from the reports by Zimmer (1950, 1953). He reported that redds were first observed on 3 October, 1947 (a flight was conducted during September, but no spawning was observed); first spawning was observed on 13 October, 1948 (1 redd observed); the earliest survey in 1949 occurred on 13 October, and 148 redds were observed (indicating that spawning likely began prior to that date); the earliest survey of 1950 was conducted on 29 September, but no redds or live salmon were observed; early surveys in October of 1951 were not successful in identifying spawning due to high turbidity; the earliest surveys conducted in 1952 occurred between 8-12 October, the water clarity was described as very clear, and no indications of spawning were detected. In his early report Zimmer (1950) concluded that, "… the spawning period of fall Chinook salmon in the Snake River above Hells Canyon Dam site starts in late September ***or*** early October and is completed by early December." This was written after the surveys of 1949. Based on following years' data, and looking at all of his data as a whole, it appears more reasonable that historically, spawning in the Marsing Reach of the Snake River typically began during the first or second week of October, which is similar to what is observed in the contemporary spawning areas downstream of the Hells Canyon Dam.
8. Data that Zimmer (1950, 1953) provides indicates that peak spawning in the Snake River occurred at a similar time historically (late 1940s', early 1050s') as compared to what is presently observed (during first to second weeks of November).
9. Based on the best data available, there is no evidence that contemporary spawn timing has been altered, with respect to historic timing, downstream of the Hells Canyon Dam.

Incubation Survival:

1. CRITFC is inappropriately critical of merging data from several studies in order to present a more complete analysis/synthesis of a hypothesis or theory. Merging data from studies is quite valid, especially if those studies proposed similar hypotheses, were performed on similar species, and were conducted under similar conditions.
2. By merging the data from the three studies in question (Olson and Foster [1955], Olson et al. [1970], and Geist et al. [2006]), rigorous statistical analyses can be completed that lead to unambiguous results; an unbiased, thorough, scientific approach can be used to make an objective observation on how naturally declining water temperatures may affect incubation survival of fall Chinook salmon embryos.
3. CRITFC is correct in pointing out that one set of data (23 November) from the Oslon et al. (1970) report was noted by the authors as “erratic”, and was omitted from their analysis. IPC also omitted that data from its analysis and it makes no difference in the final results or conclusions.
4. CRITFC argues that the use of the 30 October test of Olson et al. (1970) is the single best test to use as a surrogate for Snake River fall Chinook salmon embryo mortality dependant on temperature conditions. CRITFC notes that it is “reasonable” to conclude that a significant increase in mortality occurred between the initial test temperatures of 56.6 and 58.6 °F (13.7 and 14.8 °C). It seems that the temperatures within each test group of this test date “ticked” upward, and the actual highest temperature for these two tests were about 57.5 and 59.5 °F (14.2 and 15.3 °C). Total mortality between these two tests (without replication – a very important item to note) was 3.6% and 11.0%, respectively (a difference of 7.4%). It is also just as reasonable to conclude that because there was no replication this difference in mortality is not significant, and is wholly explainable by normal variation within a population. This is the single most important reason to have replication within a biological/ecological study design – to be able to account for natural variation. CRITFC also inappropriately discounts the fact that the water temperature “ticked” up during the test; however, it is very important in reviewing the results to take into account that the temperature did indeed “tick” upward by as much as 0.5 °C even if it had done so only for a single day. More importantly, for the series of tests begun on 30 October, a large increase in total mortality was noted between series three (11.0%) and four (28.1%), indicating a difference in mortality of about 17.1%. Even without replication, it is reasonable to conclude that this is likely a significant increase in mortality. The series four embryos were subjected to early incubation temperatures as high as 61.6 °F (16.4 °C), and this continues to support and illustrate that within a natural thermal environment the temperature exposure break-point in increasing embryo mortality lies between 16.0 and 17.0 °C. There is nothing untoward with this interpretation of the data.
5. CRITFC discusses the Olson et al. (1970) 8 December test groups in a very odd manner, indicating that total mortality “doubled” (and remained “doubled”) with an increase of initial exposure temperature of 12.3 to 13.4 °C. The mortality changed from 7.3% to 17.0% (a difference of 9.7%), respectively for those two test groups, but at higher initial test temperatures dropped to 14.1% (at 14.5 °C)

and 12.4% (at 15.6 °C). While a difference in mortality as high as 9.7% may at first seem excessive, the difference at the highest temperature fell to 5.1%, and does not seem excessive (nor is it "doubled"). This test illustrates the need for replication within groups, as without replication within each test group, it is impossible to know what part natural variation plays in the interpretation of these results and whether there are actual differences in these results that can be attributed to the exposure condition.

6. Concerning the 8 December test groups in the Olson et al. (1970) study, if we were to continue with CRITFC logic, then the best temperature at which to begin incubation would actually be 8.9 °C. Those test embryos had a total mortality of 4.8%, which was the lowest compared to all others in that test group. However, during the 30 October test, the group that had the highest test temperature of 14.2 °C had the lowest total mortality –3.6% --observed throughout the entire study. That should certainly be the "best" temperature at which to begin incubation. But, we can become more confused: another group begun at 13.9 °C on 14 November (only 0.3 °C cooler than 14.2 °C but higher than 8.9 °C) had total mortality of 16.4%. Mortality increased from 4.8% at 8.9 °C to 16.4% at 13.9 °C and then dropped to 3.6% at 14.2 °C. To make matters more confusing, there were two different groups that had equal total mortalities of 11.0% but which had very different high test temperatures – one was 12.8 °C and the other was 15.3 °C. In the final analysis, which data point should we choose as best? This illustrates why the introduction of replication into the study design, which would help account for variation, would make the results more easily understood.
7. When stating that the HCC is presently more amenable to a sub-yearling life history strategy for fall Chinook than was historically the case, it is imperative to understand that IPC is talking about the reach of the river downstream of the HCC. IPC is making a comparison between the Hells Canyon Reach as it presently is, and the Hells Canyon Reach as it historically was.
8. IPC must emphasize that naturally declining thermal regimes result in very different embryo survivals than what may result from constant temperature studies.
9. There is no doubt that the process of setting a protective temperature standard was based on an abundant source of literature. Further, without relevant data, it would seem reasonable that using the only available information (even if from constant temperature studies) would be a prudent way to set a temperature standard. However, when provided with a good, solid body of evidence that is contrary to the standard, and is applicable to a specific species within a natural setting, it also seems prudent and reasonable to use that data to set a "site-specific" standard that remains protective of the species.
10. CRITFC mentions that when discussing temperatures we should be concerned with the daily fluctuations in temperature, and how they might affect incubation survival. This is a case in point illustrating CRITFC's lack of first-hand understanding of the Snake River system, especially during the fall. The diel temperature fluctuation of the Snake River during the fall is generally about 0.4 °C (Groves et al. in press), and it tends to cool at a rate of about 0.2 °C per day. This is a very consistent level of diel fluctuation, as well as rate of decline.

CRITFC notes that a decline in temperature of 0.2 °C per day, over a 5-day period is analogous to a constant temperature regime. This is not likely, as it represents a change over a 5-day period of 1.0 °C; this is a considerable amount of cooling in a large river.

11. CRITFC again falls back on an odd "what if" type of analysis to cast doubt onto naturally varying temperature experiments, saying that one test might have a daily fluctuation of ±1.0 °C, whereas another might have a daily fluctuation of ±4.0 °C. CRITFC notes that these would be very different experiments, and would likely provide different results. IPC would agree. However, the three incubation survival studies that have been conducted on fall Chinook salmon, using naturally variable temperature conditions (Olson and Foster [1955], Olson et al. [1970], and Geist et al. [2006]) mimicked the thermal character of a large river (either the Columbia within the Hanford Reach, or the Snake River within the Hells Canyon Reach). These two river sections have very similar daily fluctuations that do not fluctuate by more than about 0.5 °C per day. Please note that this type of fluctuation refers to a variation around the daily mean temperature of +0.25 and -0.25 °C per day. The data resulting from those studies are very relevant (more relevant than constant temperature studies on sockeye salmon, for example) to setting more realistic temperature standards for fall Chinook salmon of the Snake River.
12. With respect to Combs (1965) and the constant temperature conditions that his test organisms were exposed to, that author was obviously referring to the fact that a constant temperature regime maintained throughout the entire incubation period could not realistically be expected to occur in a natural stream or river environment.
13. It is our understanding that the notation by Beacham and Murray (1990), concerning the fact that their test conditions would not be expected to be representative of a natural environment, was made in order that over-zealous resource managers would not be so quick to use their information as representative of what might occur in a natural environment. The authors were not "caught red-handed" (CRITFC page 17); they were simply stating that their tests were not representative of what occurs in nature.

Effects of Intragravel Water Temperature:

1. CRITFC misunderstands this section of the Temperature White Paper. Data collected in the Snake River by Hanrahan et al. (2004) was collected at known fall Chinook salmon spawning grounds. However, the data was collected from undisturbed, ambient substrate, and from several different depths in the gravel matrix, most of which were deeper than what would normally be considered egg-pocket depth. Data that CRITFC continues to rely on to support the contention that redd temperatures are significantly warmer than water column temperatures come from studies that have collected data from the ambient, undisturbed substrate – not from natural or artificial redds (Geist et al. 1999; Geist 2000; Hanrahan et al. 2004; Arntzen et al. 2006; Hanrahan 2007). The data collected in the Snake River by IPC, described by Groves et al. (2007), and also described by Groves et al. (in press) was also collected at fall Chinook salmon spawning grounds, but from artificially created redds located throughout those spawning

grounds in very close association with naturally created redds. The data provided by IPC most closely simulates the thermal conditions that would be expected to be present in naturally constructed redds. As well, other authors who have attempted to study either natural or artificial Chinook salmon redds have noted the same type of findings (Ringler and Hall 1975; Vronskiy and Leman 1991; and Hanrahan 2007).

2. Chinook salmon do not “exclusively” spawn in downwelling zones; however, those types of environments are more commonly used by Chinook salmon, and this has been shown in several different studies, in several different river systems (Vronskiy 1972; Leman 1988; Vronskiy and Leman 1991; Geist 2000; Geist et al. 2002; Hanrahan et al. 2004). Additionally, several researchers have demonstrated that the physical structure of large salmonid redds tends to alter the local hydraulics that are typical over relatively flat, undisturbed gravel beds. The physical structure of a salmonid redd acts to increase the infiltration of surface water into the gravel structure of the redd (Stuart 1953; Vaux 1968; Cooper 1965). The infiltration of surface water into the redd structure can be at least as deep as about 46 cm (Cooper 1965). Redistribution and cleaning of the substrate during redd construction, the increased infiltration of surface water due to the redd structure, and the disposition to spawn where down-welling occurs naturally all facilitate increased interaction between surface water and the incubation environment within Chinook salmon redds, as especially noted within the Snake River. This can result in physicochemical similarities between surface waters and the intra-redd environment, specifically with relation to temperature. This is true whether redds are created in an upwelling or downwelling environment.
3. In all instances of creating artificial redds, it has been noted that during the early part of the redd “life” the water temperature conditions found within redds is generally equivalent to the water column conditions, and within the accuracy limits of instrumentation (0.2 °C). Please note figures 16-23 on pages 70-74 of Groves et al. (2007), and data reported by Groves et al. (in press). These quotes are taken directly from Groves et al. (in press):
    a. “During the first 14 days of the 2003-2004 incubation period, the mean daily absolute temperature difference between the intra-redd and surface water environments of the Lower Hells Canyon section (below the Salmon River; LHC) was 0.10°C (SE=0.01). Within the Upper Hells Canyon section (UHC), the mean daily absolute temperature difference between the intra-redd and surface water environments during the first 14 days of the incubation period was 0.08°C (SE=0.01).”
    b. “During the first 14 days of the 2004-2005 incubation period, the mean daily absolute temperature difference between the intra-redd and surface water environments of the LHC was 0.12°C (SE=0.01). Within the UHC, the mean daily absolute temperature difference between the intra-redd and surface water environments during the first 14 days of the incubation period was 0.13°C (SE=0.01).”
    c. “During the first 14 days of the 2005-2006 incubation period, the mean daily absolute temperature difference between the intra-redd and surface water environments was 0.14°C (SE=0.01).”

Emergence/Outmigration Timing:

1. Emergence timing in the present-day Hells Canyon Reach is similar to what occurred historically in the Marsing Reach (refer to White Paper Figure 5, page 16), and has become more similar during recent years.
2. Outmigration timing of juvenile, sub-yearling Snake River fall Chinook, observed at Lower Granite Dam, has been occurring earlier during the past few years (2000-2006) than what was observed during the early through late 1990's. From 1995-2006 the mean passage date of wild pit-tagged sub-yearlings has steadily changed from Julian date 207 (25 July) to 172 (20 June). The trend seen for the mean is also apparent in the middle 80% of the run. During 1995 the middle 80% of the run occurred from Julian day 182-241 (30 June – 28 August; 59 days), while in 2006 it occurred from Julian day 151-184 (30 May – 2 July; 33 days). Not only has the timing become earlier, it has become less protracted. These trends are also characteristic of the entire sub-yearling smolt passage index. From 1995 through 2006 the outmigration timing of sub-yearling Chinook salmon has become earlier by about 35 days. . The reason for this shift in outmigration timing is unknown; however, it is occurring earlier and more like what was historically observed prior to when the Hells Canyon Complex or the Lower Snake River dams were constructed.
3. There is no doubt that the slack water condition of Lower Granite Reservoir has a delaying effect on the rate at which sub-yearling fall Chinook salmon migrate downriver. Were it not for the slack water conditions of Lower Granite Reservoir, the sub-yearling fall Chinook salmon emigrating from the Hells Canyon Reach during contemporary times would be passing through the Central Ferry region of the lower Snake River (downstream of the present-day Lower Granite Dam) at a time that would be comparable to what Mains and Smith (1964) described for sub-yearlings that allegedly emigrated from the Marsing Reach prior to the construction of the Hells Canyon Complex.
4. CRITFC urges that IPC should take steps to mitigate for the slack water conditions of the Lower Granite Reservoir. But that is a federal responsibility, not an IPC responsibility.
5. CRITFC indicates that the trend in earlier emigration timing is due to the recent observation of a yearling life history strategy, especially exhibited by very late emerging juveniles originating from the Clearwater River. The expression of a yearling life history strategy has absolutely nothing to do with the fact that the sub-yearling fish from the Snake River are exhibiting earlier emigration timing.
6. Prior to the Hells Canyon Complex being constructed, the mean water temperature through the Hells Canyon Reach during the period 15 December through 15 February was approximately 1.7 °C. Presently, the mean temperature during this same time period, for the river reach from the Hells Canyon Dam to the Salmon River confluence, is approximately 4.6 °C, and for the Snake River downstream of the Salmon River it is 3.9 °C. This represents a significant warming of the base winter flows of the Snake River downstream of the Hells Canyon Dam. For comparative purposes, the mean water temperature of the Marsing Reach, for the period 15 December through 15 February, was about 4.4

°C. It would seem that the Hells Canyon Reach is presently more like the historic Marsing reach environment than it was prior to when the Hells Canyon Complex was constructed.

A Review of Comments by Dale A. McCullough (August 27, 2007) on White Paper by Groves et al. (July 2007)

Charles C. Coutant
June 8, 2010

These comments are provided at the request of Idaho Power Co. (IPC) though its legal representative, Barker Rosholt & Simpson LLP, for a peer review of its proposal for a site-specific and date-specific temperature criterion (standard) for the Snake River below the Hells Canyon Complex (HCC). These comments are part of the review of the proposal. The proposal is for a site-specific temperature standard under Idaho and Oregon temperature criteria that would modify the existing standard below Hells Canyon Dam during one week in October (October 23-29) from 13.0°C to 14.5°C (for the averaged 7-day daily maximum temperature). As part of its re-licensing proceeding with the Federal Energy Regulatory Commission (FERC; Project No. 1971), IPC commissioned a "white paper" review of the effects of the HCC on water temperature and fall Chinook salmon (Groves et al. 2007). Fall Chinook salmon currently use the river downstream from Hells Canyon Dam for spawning, incubation, and early downstream migration. Dale McCullough, representing the Columbia River Inter-Tribal Fish Commission (CRITFC) and the Nez Perce Tribe, provided comments on the white paper (McCullough 2007). It included quotes from the white paper, comments related to those quotes, literature references, and excerpts from supporting literature.

It is important at the outset to recognize that both the Groves et al. (2007) review paper and McCullough's review of it cover a much broader subject matter than the proposal for a site-specific criterion. Much of the Groves et al. white paper deals with broader questions of temperature change in the Snake River and its effects on fall Chinook salmon (as appropriate for the FERC proceeding), and McCullough's review of it does likewise. McCullough further broadens the topic by invoking information on other races of Chinook salmon and by introducing speculative suggestions, particularly that the HCC should be modified to control water temperatures throughout the lower Snake River, especially in summer, beyond the temperature changes it already creates. In his first paragraph, McCullough specifically links "providing warmer water temperatures in the spawning season, allowing the thermal shift to persist," and "summertime thermal problems below HCD." In general, his comments appear to lack focus and are often difficult to follow. He responds in several places to a previous suggestion that 16.5°C in the first week of incubation is acceptable rather than the current proposal for 14.5°C. Nonetheless, he helps define the opposing contentions and makes several important points to be considered in evaluating the merits of the proposal.

My comments focus on the portions of McCullough's review that are directly pertinent to the proposal and backed by relevant technical evidence. As noted in my review of the proposal and its supporting information, there is a gradation of what information on temperatures, and temperature effects in the Snake River basin is pertinent. The current issue should not be taken in total isolation of its potential long-term consequences for other aspects of temperature effects on salmon in the lower Snake River. But those connections and possible secondary consequences should not be taken so far afield as to cloud the issue of the present proposal. My review of McCullough's comments was conducted before I had read the IPC responses (which seem appropriate and scientifically correct), and thus is based on my personal knowledge of the subject, including relevant literature. The headings that follow conform to the headings in McCullough's comments.

Adult migration timing (pages 1-3): The discussion of temperatures during adult migration to the reach below the HCC between mid August and September historically and currently is not relevant to the proposal. The proposal does not seek change in the broad management of temperature in the lower Snake River (including cold releases from Dworshak Dam). The thermal history of the Snake River from pre-dam conditions to the present is not relevant. The increasing understanding of adult migration timing and rates, and their relation to temperatures, flows, etc. raised by both Groves et al. and McCullough (with technical references) are interesting in the broad perspective but not relevant to the proposal for a site-specific temperature standard at Hells Canyon dam for one week in October. What is relevant is that adult fall Chinook salmon now occur in increasing numbers in the reach below the HCC for purposes of reproduction and as a result their thermal habitat during the reproduction season needs protection through technically justifiable water temperature criteria and standards.

Pre-spawn mortality (page 3-5, 7): The issue of pre-spawning mortality or energetic stress for salmon holding below HCC at temperatures above 19°C is not directly relevant to the proposal. The proposal seeks a change in the temperature standard for one week in October (23-29) from 13°C to 14.5°C. Other times are covered by other standards: 20°C until October 23 and 13°C after October 23 (currently). These discussions of pre-spawning conditions by both Groves et al. and McCullough would pertain to the sufficiency of the 20°C standard in view of migration dynamics and holding patterns by migrants. But that is a different issue for a different time.

Egg mortality (page 6-7): Data on egg mortality (actually eggs and the embryos that develop from them) are directly pertinent to the proposal. Both Groves et al. and McCullough agree that mortality at a potentially lethal temperature is a function of duration of exposure. To illustrate the point, Groves et al. provide data from a study by Healey (1979; see references in Groves et al.) conducted at a uniform temperature of 15.6°C from the start (a temperature at which the Sacramento River stock experiences long-term egg and embryo mortality). That study showed just three points with an increased percentage of mortality the longer the eggs and embryos were held at the constant temperature. Groves et al. make the scientifically correct statement that because there were no replications for each temperature treatment, no statistical analysis could be carried out to see if the three results were statistically different (although the three times on the graph are persuasive for the trend). McCullough criticizes the statistical comment by way of suggesting an alternative experimental design with a different objective than the Healey study. McCullough proposes using different temperatures rather than different exposure durations in order to determine the threshold temperature. Although McCullough's alternative study objective is pertinent to the proposal, his criticism of Groves et al. and Healey (1979) is not on target for the particular discussion. In fact, the studies cited in the proposal (Olson and Foster 1955, Olson et al. 1970, and Geist et al. 2006; see references in Groves et al. 2007) are even more pertinent than McCullough's suggestion, when the objective is determining a threshold temperature for spawning and initial incubation in a declining thermal regime.

McCullough presents a convoluted argument on the top of page 7 that I could not follow, including that a temperature reduction of 0.2°C per day is a "relatively constant temperature over the initial 5 days." While strongly supporting EPA's determination of 13°C as the "upper end of optimum" he provides no justification from the scientific literature for this number or even a synopsis of EPA's reasoning.

Gamete viability (page 8): This topic deals with the viability of gametes (eggs and sperm) of adult Chinook salmon that migrate or are held at temperatures generally above 20°C in August-October prior to spawning. The topic is not relevant to the proposal for site-specific regulation of temperatures in spawning waters below the HCC in late October. As with issues of pre-spawn mortality or energy use in migratory adults, this issue and the cited references would be relevant to evaluating the existing 20°C mainstem temperature standard, not the proposed site-specific standard.

Disease susceptibility (page 8-10): This topic, again, concerns impacts of temperature on migrating or holding adults in the lower Snake River prior to spawning in the reach below the HCC and is not relevant to the current proposal. The Groves et al. review and the points raised in the McCullough critique might be relevant to re-evaluation of the 20°C limitation on mainstem temperatures during the migration period prior to spawning, but not to the issue of temperatures to protect spawning and incubation for one week in late October.

Spawn timing (page 10-13): The date when spawning first occurs is marginally relevant to the proposal. As shown by both the Groves et al. report and McCullough's comments (each with documentation), there is considerable variability in the timing of initial fall Chinook salmon spawning and the distribution of spawning throughout the spawning period both historically and under present development. This is especially true when one considers the various locations where fall Chinook salmon spawn in the vicinity of the HCC (including tributaries with quite different temperature regimes). Pinning down initial spawning dates from literature sources is made complicated by inadequacies (as viewed with today's objectives) in most of the early field studies.

The variability in spawning dates is more relevant to the selection of the regulatory date for spawning than it is to the proposal's objective of changing the temperature allowed at that time. Despite known variability (due, most likely, to many factors), both Idaho and Oregon have set the date of initial spawning as October 23 for regulatory purposes, presumably based on their independent assessment of the literature cited by both Groves et al. and McCullough. McCullough notes that by using the 16-year data set reproduced by Groves et al. (Table 3, page 41) the average date of first spawning actually is October 23. McCullough selectively uses various combinations of years from this data set to illustrate his points about spawning at warmer or cooler temperatures and at different dates. His further discussion simply illustrates that the dates and temperatures of initial spawning cannot now be reliably related to impacts on the overall population.

The proposal does not propose any change in the October 23 date for regulatory control of spawning temperature. Based on the literature cited by both parties, October 23 appears to be an acceptable average date for regulatory purposes.

Incubation survival (pages 13-17): This issue is directly relevant to the proposal, for it is the survival of eggs and embryos during the first week (on average) of incubation that is to be protected by the standard (existing or proposed). McCullough raises several objections to the analysis by Groves et al.: (1) the combining of data from the Olson and Foster (1955), Olson et al. (1970), and Geist et al. (2006) studies; (2) interpretation of fluctuating temperatures ("upticks") in the Olson et al. (1970) studies; (3) cooler thresholds in Olson's November and December tests; (4) discounting incubation studies at constant temperatures; and (5) stock-specific thermal requirements for incubation (temperature tolerance and development rates). (In this section, McCullough also interjects comments on the Groves et al. assertion that the HCC complex fosters the age-0 life cycle, but that subject is beyond incubation survival.)

Combination of data: McCullough asserts that the studies by Olson et al. (1970) showed negative effects at lower temperatures than did Geist et al. (2006) and that Groves et al. "dealt with" this discrepancy by inappropriately merging data from all three studies. Merger of similarly derived data is often appropriate when individual data sets are small, but it is usually preceded by statistical tests of homogeneity. If the results are statistically homogeneous, then merger is justified. There is no evidence presented that Groves et al. did such a statistical test among the three data sets, so McCullough's criticism of merger might be justified on that basis. A visual inspection of the data as presented in Figure 5 of the proposal (and a similar one in Groves et al. but without the spline modeling), however, suggests that the results of the three studies were remarkably similar with the exception of the 17°C data point from the Geist et al. study (which is above the temperature range in contention). The figure does not support McCullough's assertion (page 13, bottom paragraph) that Groves et al. somehow hid ("dealt with") negative effects at lower temperatures than found by Geist et al. by doing the merger. McCullough's impression apparently comes from Olson et al. having conducted trials that started at lower temperatures than did Geist et al. (<13°C) or the location of the change in mortality (quantitatively determined as the breakpoint in the spline model shown in the proposal). The figure in the proposal indicates a base mortality averaging about 10% (confidence limits from zero to 18-20%) from the lowest initial temperature of 9°C in the Olson et al. tests through about 16.5°C in tests by Geist et al.. Such a baseline mortality level is commonly seen in incubation tests, as noted in the Groves et al. review. There is a slight (and insignificant, based on the confidence intervals) trend toward more mortality at the higher end of the 9-16.5°C range. Despite Geist et al. showing baseline survival at 16.5°C, the spline model (not shown in the Groves et al. paper but included in the proposal) indicated a break point at 16°C, based on the data from the two Olson studies. Whether the studies are viewed separately or merged, the clear impression is given that mortality rises above the normal baseline of 0-18% near 16°C. The merger of the data for the spline analysis did not "obliterate results" from Olson et al. (1970), as contended by McCullough (top of page 14) but lowered the estimated break point compared to the results of Geist et al. alone.

Interpretation of "upticks" in temperature data in Olson et al. (1970): Although Olson's studies were conducted at a time when temperatures of the Columbia River water (that supplied the laboratory) were falling, daily differences in river temperature occasionally caused a slight and temporary rise in temperature after the eggs began to incubate. These early "upticks" essentially introduced a new and higher starting temperature for the series. Any thermal damage to the early embryos would have occurred shortly after development had started. McCullough repeats (upper part of page 14) results of Olson et al. (1970) that do not appear to conflict with interpretations by Groves et al..

Cooler thresholds in Olson's later tests (page 14): McCullough briefly notes that the trials reported in Olson et al. (1970) that started in November and December showed increased mortality at lower temperatures than did the tests that started in October. His implication is that the warmer thresholds seen in earlier tests are likely in error (although he does not say so directly). This observation, while interesting and perhaps pointing to a cooler acclimation state for spawners and their gametes, is not particularly relevant to a temperature threshold for incubation in the early spawns, which is the subject of the proposal.

Discounting of incubation tests at constant temperature (page 15-16): McCullough criticizes Groves et al. for repeatedly discounting the scientific literature that compares survival during incubation at various constant temperatures. McCullough's reasoning is partly sound. Constant-temperature experiments have provided the basic underpinning of our understanding of many types of temperature effects. Their quantitative results can be used incrementally, as McCullough notes, to estimate the effects of many types of fluctuating temperatures. Tests conducted under changing temperatures can be generalized less well, and often can be related only to the specific temperature conditions of the test. The historical studies at constant temperature, reviewed in Groves et al., are most useful for parameterizing models that estimate development time in different (often fluctuating) temperatures; they are less useful for estimating mortality thresholds. That said, it is still appropriate for Groves et al. to emphasize the value of tests that attempt to mimic the temperature changes actually seen in the Snake River below the HCC. In an ideal situation, one could use results of constant-temperature tests incrementally to estimate thresholds and then apply a validation step testing incubation success using the actual temperature change. In a sense, that is what has been done by Groves et al. in reviewing all the literature and then focusing on the three studies that used normal declining temperatures. Neither the incremental application of constant-temperature mortality data nor tallying mortality during the simulation of actual temperature changes illuminates the specific stages of development that are most sensitive to higher temperatures. There are indications in the literature that specific early embryonic stages of salmon are the most sensitive but that the effects of damages at that stage do not appear until later in development (as noted in

Olson et al. 1970). Such academic details need not cloud the overall mortality threshold seen near 16°C in the most realistic temperature exposures. The proposal appears to apply an appropriate safety factor for protection of incubating salmon eggs and early embryos when it proposes a criterion/standard of 14.5°C for the first week (on average) of spawning.

Stock-specific thermal requirements (16-17): McCullough raises the issue of stock-specific differences in thermal requirements for incubation, but does not make clear his disagreement with the Groves et al. review. Local adaptation is widely assumed in salmonid literature, but poorly identified for thermal requirements. McCullough correctly indicates that the divergence is greatest among species and less for interspecific populations. The relevance of this issue would seem to be the reliability of data from Hanford-spawning fall Chinook salmon for estimating thermal limits for the Snake River stock below HCC. A crucial point would be the reproductive isolation of the Hanford and Snake River spawners. It is my understanding from telemetry studies that there has been considerable mixing of fish from the two locales and that an evolutionary divergence of traits such as thermal tolerance would be unlikely.

Effects of intragravel water temperature (pages 18-19): This issue is clearly germane to the proposal, because the eggs and embryos incubate in the gravel of redds, not in the overlying water. As Groves et al. and McCullough correctly note, the intragravel temperatures of simulated redds in the Snake River below the HCC during the fall have been shown to be about a half degree C higher than channel-water temperature, reflecting a relative lag in water passage through the gravel as well as heat retention by the solid material. McCullough is correct that this difference could be biologically significant should IPC recommend an initial incubation temperature of 16.5°C, as he indicates (page 19). His objection is moot, however, because IPC's proposal requests 14.5°C, not 16.5°C, as a site-specific standard for the incubation temperature during the first week of spawning (on average).

Emergence-outmigration timing (pages 19-22): It is reasonable and relevant to consider the effects of a change in allowable temperature in late October on the timing of emergence and outmigration. This is because warmer (but non-lethal) temperatures at that time would cause more rapid development of early embryos, which could, later incubation temperatures being the same, result in somewhat earlier emergence and downstream migration. Groves et al. delve into broad considerations of the relationship between emergence and passage downstream (historically and presently) in the Snake River and McCullough does likewise. Many of their points do not apply to the present proposal, however. Historical conditions prior to the HCC are not germane because the proposal concerns a change in allowable temperatures with the existing development. No action on the proposal would restore historical conditions (particularly since, as McCullough indicates, the temperatures and emergence times pre-HCC are poorly understood). A river without the HCC is not in the cards, despite what some might like to see. Although McCullough wishes that IPC would provide more temperature control of river water through the HCC to benefit emergence and migration (e.g., with unspecified temperature control devices), that decision is far afield from the actions requested in the proposal. Migration dynamics through Lower Granite Reservoir are certainly important for the population of spawners below the HCC, but problems there can hardly be rectified by any decision regarding the present proposal. What appears to be most relevant to the proposal is the demonstrable fact that somewhat warmer temperatures in the early stages of incubation (below a lethal temperature) would contribute in a small way to earlier emergence in spring and thus to an earlier migration time. An earlier start to migration below the HCC is deemed desirable to help juvenile salmon pass down the lower Snake River earlier in the season when temperatures are cooler and survival higher than in mid-summer. The small contribution to earlier migration from initially warmer incubation temperatures would likely be entirely swamped, however, by the many other contributing factors to migration timing raised by both Groves et al. and McCullough.

Ehist (page 22): McCullough's comments on the thermal modeling of Snake River water (from the TMDL proceeding) are not relevant for the proposal, except that they confirm that water retention in the HCC creates a lag in the seasonal temperature pattern for the Snake River downstream. This lag, as is well known, causes temperatures below HCD to be higher in fall than they are at the inflow to Brownlee Reservoir on the same date. As McCullough notes, this change might have caused spawning in the river below HCC to be later than would have occurred historically. But the reach was not used for spawning historically, and the proposal deals with uses and water temperatures as they exist currently.

References

Groves, P. A., J. A. Chandler, and R, Meyers. 2007. White Paper: The effects of the Hells Canyon Complex relative to water temperature and fall Chinook salmon. Final Report. Hells Canyon Complex, FERC No. 1971.

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